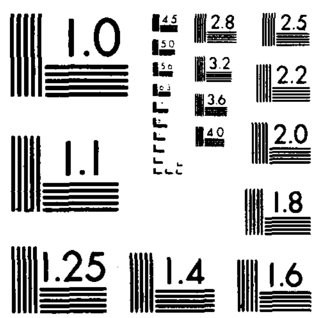
AD-A084 933 NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER ATL--ETC F/G 13/2
EXHAUST EMISSIONS CHARACTERISTICS FOR A GENERAL AVIATION LIGHT---ETC(U)
APR 80 E E BECKER
UNCLASSIFIED FAA-NA-79-46 NL

1 OF 2
AD A084933



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS

Report No. FAA-NA-79-45

EXHAUST EMISSIONS CHARACTERISTICS FOR A GENERAL AVIATION LIGHT-AIRCRAFT AVCO LYCOMING 0-320/10-320-DIAD PISTON ENGINE

LEVEL II

ADA084933

Eric E. Becker

FINAL REPORT

APRIL 1980

Prepared for
U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-NA-79-45	AD-A084 933	

4. Title and Subtitle	5. Report Date
(6) EXHAUST EMISSIONS CHARACTERISTICS FOR A GENERAL AVIATION LIGHT-AIRCRAFT AVCO LYCOMING O-320/IO-320-DIAD PISTON ENGINE	(11) Apr[redacted]80
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
(10) Eric E. Becker	(14) FAA-NA-79-45

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Federal Aviation Administration National Aviation Facilities Experimental Center Atlantic City, New Jersey 08405	
	11. Contract or Grant No. 201-521-100

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590 (12) 124	(9) Final rept.
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Avco Lycoming O-320/IO-320-DIAD engine (S/N889-X) was tested at the National Aviation Facilities Experimental Center (NAFEC) to develop an exhaust emissions data base. This data base consists of current production baseline emissions characteristics, lean-out emissions data, effects of leaning-out the fuel schedule on cylinder head temperatures, and data showing ambient effects on exhaust emissions and cylinder head temperatures. The engine operating with its current full-rich production fuel schedule could not meet the proposed Environmental Protection Agency (EPA) standard for carbon monoxide (CO) under sea level standard-day conditions. The engine did, however, meet the proposed EPA standards for unburned hydrocarbons (HC) and oxides of nitrogen (NO_x) under sea level standard-day conditions. The results of engine testing under different ambient conditions are also presented, and these results show a trend toward higher levels of emissions output for CO and HC under warm-or hot-day conditions while producing slightly lower levels of NO_x.

17. Key Words		18. Distribution Statement
General Aviation	Piston Engines	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161
Oxides of Nitrogen	Carbon Monoxide	
Emissions (Pollution)		
Unburned Hydrocarbons		

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	120	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

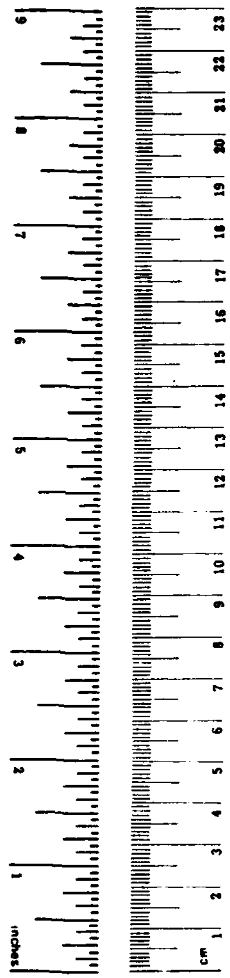
240550

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

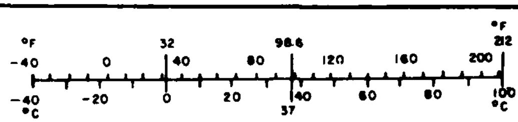


TABLE OF CONTENTS

	Page
INTRODUCTION	1
Purpose	1
Background	1
DISCUSSION	2
Description of Avco O-320/IO-320-DIAD Engine	2
Description of Test Set-Up and Basic Facilities	2
Description of Air Induction System and Airflow Computations	5
Description of Fuel-Flow System	5
Description of Cooling Air System	7
Description of Test Procedures and EPA Standards	7
Description of Emissions Measurement System (Reference 3)	9
Description of Sample Handling System	15
Description of Filtration System	15
Computation Procedures	15
RESULTS	22
General Comments	22
Results of Baseline Tests (Landing-Takeoff Cycle Effects)	22
Results of Lean-Out Tests	23
SUMMARY OF RESULTS	36
Exhaust Emissions	36
Maximum Cylinder Head Temperatures	36
Critical Landing and Takeoff Cycle	39
CONCLUSIONS	39
REFERENCES	41

APPENDICES

A Fuel Sample Analysis
B Composition of Air (General Properties)
C NAFEC Test Data and Working Plots for Analysis and Evaluation for the Avco Lycoming O-320-DIAD Engine
D NAFEC Test Data and Working Plots for Analysis and Evaluation for the Avco Lycoming IO-320-DIAD Engine

LIST OF ILLUSTRATIONS

Figure		Page
1	Typical Sea Level Propeller Test Stand--Avco Lycoming 0-320/IO-320-DIAD Engine Installation-Emissions Testing	3
2	Engine Installation--NAFEC General Aviation Piston Engine Test Facility--Avco Lycoming 0-320/IO-320-DIAD Engine Test Installation	4
3	NAFEC Air Induction (Airflow Measurement) System for Light-Aircraft Piston Engine Emission Tests	6
4	NAFEC Fuel-Flow System for Light-Aircraft Piston Engine Emission Test	8
5	Schematic of Emissions Measurement Systems and Measurements Characteristics	10
6	Beckman Model 402 THC Analyzer (1.5 PSI Unmodified)	12
7	Beckman Model 402 THC Analyzer (1.5 PSI Modified)	12
8	Beckman Model 402 THC Analyzer (3 PSI Unmodified)	13
9	Exhaust Gas Molecular Weights	18
10	Relation of Carbon Monoxide and Hydrogen	20
11	Total Emissions Characteristics--Avco Lycoming IO-320/0-320-DIAD Engines Operating Under Nominal Sea Level Standard Day Conditions and the Same Average, Reference Fuel-Air Ratio for the Table 5 EPA LTO Cycle	24
12	Total Emissions Characteristics--Avco Lycoming IO-320/0-320-DIAD Engines Operating Under Nominal Sea Level Standard Day Conditions; Takeoff, Climb, and Approach Mode F/A's Same as Figure 11--Table 5 EPA LTO Cycle	25
13	Total Emissions Characteristics--Avco Lycoming IO-320/0-320-DIAD Engines Operating Under Nominal Sea Level Standard Day Conditions; Takeoff and Climb Mode F/A's Same as Figure 11--Table 5 EPA LTO Cycle	26

LIST OF ILLUSTRATIONS (Continued)

Figure		Page
14	Total Emissions Characteristics—Avco Lycoming IO-320/0-320-DIAD Engines Operating Under Nominal Sea Level Standard Day Conditions; Takeoff Mode F/A's Same as Figure 11—Table 5 EPA LTO Cycle	27
15	Total Emissions Characteristics—Avco Lycoming IO-320/0-320-DIAD Engines Operating Under Nominal Sea Level Standard Day Conditions and the Same Average, Reference Fuel-Air Ratio for the Table 4 EPA LTO Cycle	29
16	Total Emissions Characteristics—Avco Lycoming IO-320/0-320-DIAD Engines Operating Under Nominal Sea Level Standard Day Conditions; Takeoff, Climb, and Approach Mode F/A's Same as Figure 15—Table 4 EPA LTO Cycle	30
17	Total Emissions Characteristics—Avco Lycoming IO-320/0-320-DIAD Engines Operating Under Nominal Sea Level Standard Day Conditions; Takeoff, Climb Mode F/A's Same as Figure 15—Table 4 EPA LTO Cycle	31
18	Total Emissions Characteristics—Avco Lycoming IO-320/0-320-DIAD Engines Operating Under Nominal Sea Level Standard Day Conditions and the Same Average, Reference Fuel-Air Ratio for the Table 4 EPA LTO Cycle	32
19	Sea Level Standard Day Maximum Cylinder Head Temperatures for Different Power Mode Conditions and Varying Fuel-Air Ratios—Avco Lycoming IO-320-DIAD	37
20	Sea Level Standard Day Maximum Cylinder Head Temperatures for Different Power Mode Conditions and Varying Fuel-Air Ratios—Avco Lycoming 0-320-DIAD	38

LIST OF TABLES

Table		Page
1	Avco Lycoming 0-320/IO-320-DIAD Engine	2
2	EPA Five-Mode LTO Cycle	7
3	FAA/NAFEC Seven-Mode LTO Cycle	7
4	Maximum Five-Mode LTO Cycle	9
5	Minimum Five-Mode LTO Cycle	9
6	Summary of Exhaust Emissions (CO) Reduction Possibilities for an Avco Lycoming IO-320-DIAD Engine--Nominal Sea Level Standard Day (Except as Noted)--Cooling Air $\Delta P=3.0$ inH_2O	33
7	Summary of Exhaust Emissions (CO) Reduction Possibilities for an Avco Lycoming 0-320-DIAD Engine--Nominal Sea Level Standard Day (Except as Noted)--Cooling Air $\Delta P-3.0$ inH_2O	34

INTRODUCTION

PURPOSE.

General aviation piston engine exhaust emission tests were conducted at the National Aviation Facility Experimental Center (NAFEC) for the following reasons:

1. Determine and establish total exhaust emissions characteristics for a representative group of current production general aviation piston engines.

2. Determine the effects of leaning-out of the fuel metering system on exhaust emissions.

3. Verify the acceptability of test procedures, testing techniques, and instrumentation.

4. Determine reductions in operating limits and safety margins resulting from fuel system adjustments/modifications evaluated for improved piston engine exhaust emissions characteristics.

BACKGROUND.

Beginning in 1967, Congress enacted a series of laws which added environmental considerations to the civil aviation safety, control, and promotional functions of the Federal Aviation Administration (FAA). This legislation was in response to the growing public concern over environmental degradation. Thus, the FAA was committed to the development, evaluation, and execution of programs designed to identify and minimize the undesirable environmental effects attributable to aviation.

In accordance with the Clean Air Act Amendments of 1970, the Environmental Protection Agency (EPA) established emission standards and outlined test procedures when it used EPA rule part 87 in January 1973. The Secretary of Transportation and, therefore, the FAA was charged with the responsibility for issuing regulations to implement this rule and enforcing these standards.

Implementation of this rule was contingent on the FAA's finding that safety was not impaired by whatever means was employed to achieve the standards. For this reason the FAA undertook a program, subsequent to the issuance of the EPA emission standards in July 1973, to determine the feasibility of implementation, verify test procedures, and validate test results.

There was concern that the actions suggested in order to comply with the EPA emission standards, such as operating engines at leaner mixture settings during landing and takeoff cycles, might compromise safety and/or significantly reduce engine operating margins. Therefore, the FAA contracted with Avco Lycoming and Teledyne Continental Motors (TCM) to select engines that they considered typical of their production, test these engines as normally produced

to establish a baseline emissions data base, and then alter (by lean-out adjustments) the fuel schedule and ignition timing to demonstrate methods by which the proposed EPA limits could be reached. In the event that hazardous operating conditions were indicated by the manufacturer's tests, independent verification of data would be necessary. Therefore, duplication of the manufacturer's tests was undertaken at NAFEC to provide the needed verification and expand the emissions data base through independent testing.

This report presents the NAFEC test results for the Avco Lycoming IO-320-DIAD piston engine (S/N889-X). It should be noted that since the time of these tests, the EPA has rescinded the promulgated piston engine standards (reference 1). This work is reported upon herein in the same light as it would have been if the requirements were still in effect.

DISCUSSION

DESCRIPTION OF AVCO LYCOMING O-320/IO-320-DIAD.

The O-320/IO-320-DIAD engine tested at NAFEC is a naturally aspirated carburetted or fuel injected, horizontally opposed engine with a nominal 320 cubic inch displacement (cid), rated at 160 brake horsepower (bhp) for a nominal brake specific fuel consumption (bsfc) of 0.50. This engine is designed to operate on 100/130 octane aviation gasoline (appendix A—Fuel Sample Analysis of NAFEC Test Fuel). The vital statistics for this engine are provided in table 1.

TABLE 1. AVCO LYCOMING O-320/IO-320-DIAD ENGINE

No. of Cylinders	4
Cylinder Arrangement	HO
Max. Engine Takeoff Power (HP, RPM)	160, 2700
Bore and Stroke (in.)	5.125x3.875
Displacement (cu. in.)	320
Weight, Dry (lbs)—Basic Engine	291
Propeller Drive	Direct
Fuel Grade—Octane Rating	100/130
Compression Ratio	8.5:1
Max. Cylinder Head Temperature Limit (°F)	500

DESCRIPTION OF TEST SET-UP AND BASIC FACILITIES.

For the NAFEC sea level static tests, the engine was installed in the propeller test stand shown in figures 1 and 2. This test stand was located in the NAFEC General Aviation Piston Engine Test Facility. The test facility provided the following capabilities for testing light-aircraft piston engines:

(1) Two basic air sources--dry bottled and ambient air

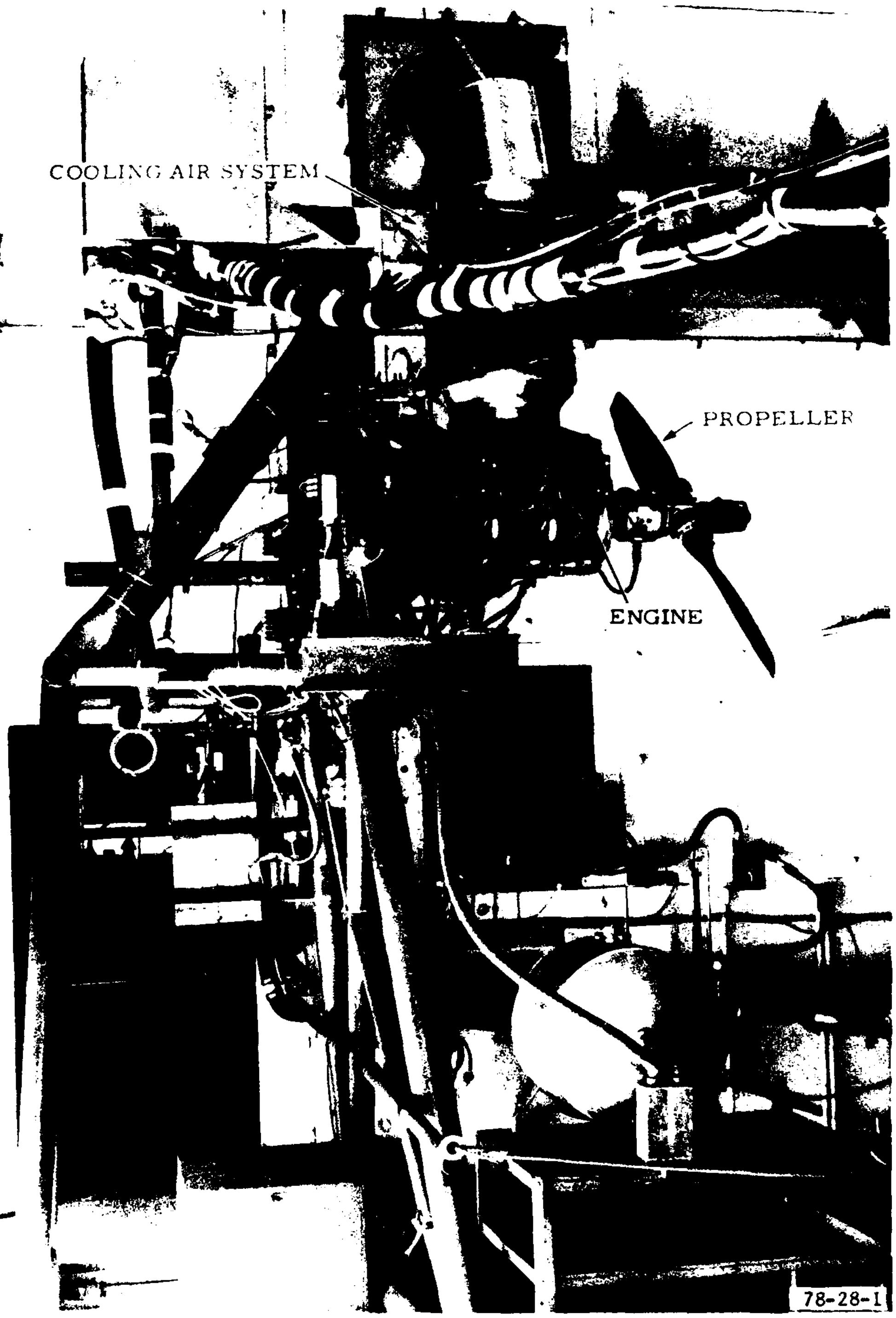


FIGURE 1. TYPICAL SEA LEVEL PROPELLER TEST STAND--AVCO LYCOMING O-320/IO-320-DIAD ENGINE INSTALLATION-EMISSIONS TESTING

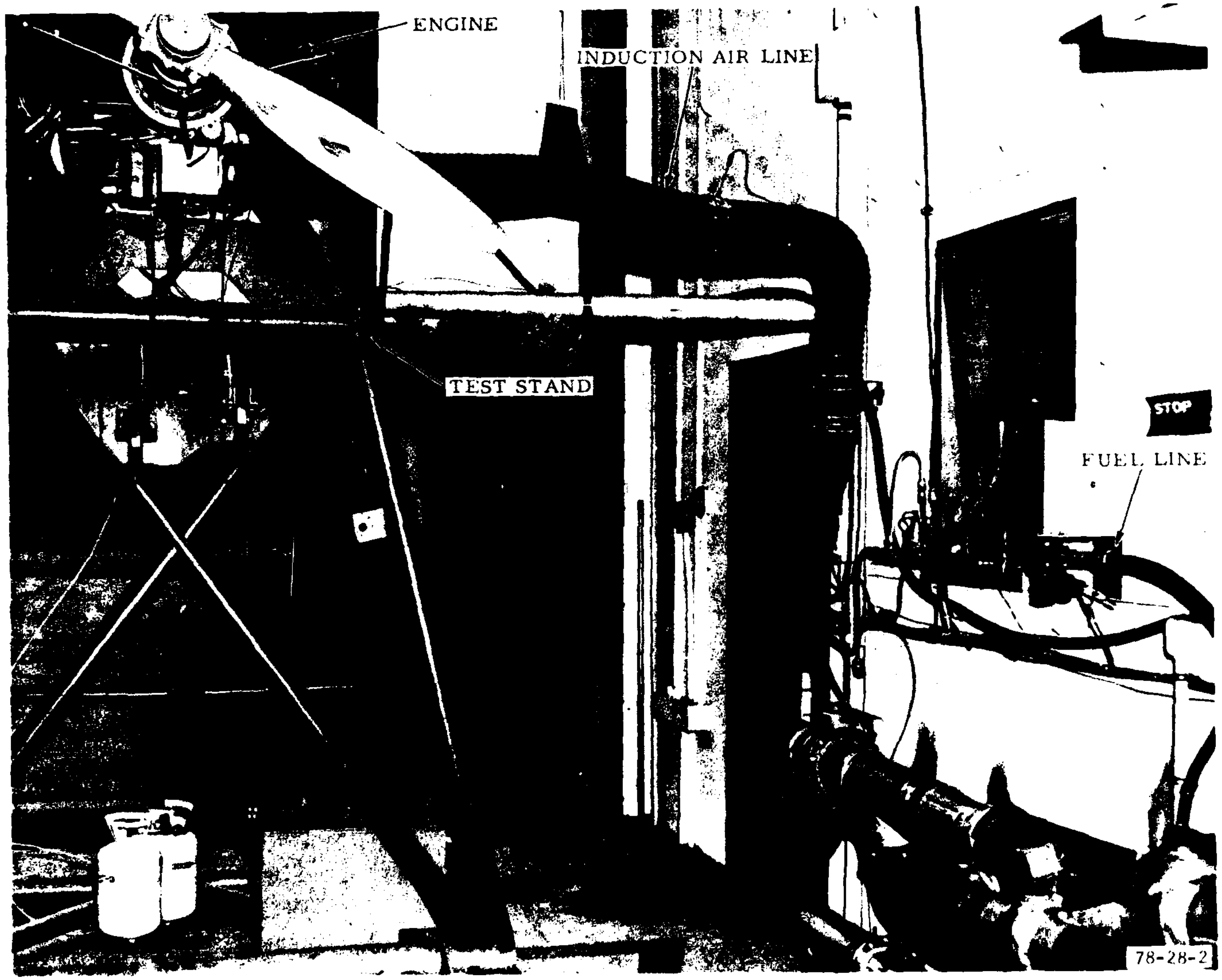


FIGURE 2. ENGINE INSTALLATION--NAFEC GENERAL AVIATION PISTON ENGINE TEST FACILITY--AVCO LYCOMING O-320/IO-320-DIAD ENGINE TEST INSTALLATION

(2) Ambient temperatures (20 to 140 degrees Fahrenheit (°F))
(3) Nominal sea level pressures (28.50 to 31.50 inches of mercury absolute (inhgA))
(4) Humidity (specific humidity--0 to 0.020 lb of water (H_2O) vapor/lb dry air)
(5) Fuel (100/130 octane aviation gasoline--a dedicated 5,000-gallon tank)

DESCRIPTION OF AIR INDUCTION SYSTEM AND AIRFLOW COMPUTATIONS.

The airflow system (induction system) utilized at NAFEC for testing light-aircraft piston engines is illustrated in figure 3. This system incorporated a redundant airflow measuring system for accuracy and reliability. In the high-flow measuring section NAFEC utilized a 3.0-inch orifice and an Autronics air meter (model 100-750S). The capability of this high-flow system ranged from 400 to 2,000 pounds per hour with an estimated tolerance in flow accuracy of ±2 percent. The low-flow measuring section utilized a small 1.375-inch orifice and an Autronics air meter (model 100-100S). The capability of this system ranged from 50 to 500 pounds per hour with an estimated tolerance in flow accuracy of ±3 percent. The size of the basic air duct was 8.0 inches (inside diameter) for the high-flow system and 2.0 inches (inside diameter) for the low-flow system.

The airflow was computed from the orifice differential pressure and induction air density using the following equation:

$$Wa = (1891)\ (C_f)\ (d_o)^2\ [(.03609)\ \Delta P \rho\ ]^{1/2} \quad \text{(Reference 2)}$$

ΔP = inH_2O (differential air pressure)
ρ = lb/ft^3 (induction air density)
d_o = inches (orifice diameter)
C_f = flow coefficient for orifice (nondimensional)
1891 = conversion constant for airflow in pounds per hour (lb/h).

For the 3.0-inch orifice this equation simplifies to:

$$Wa = (10{,}381.6)[(.03609)\Delta P_\rho]^{1/2} = 1972.23(\Delta P_\rho)^{1/2}$$

For the 1.375-inch orifice this equation simplifies to:

$$Wa = (2{,}502.6) \quad [(.03609)\ \Delta P\rho]^{1/2} = 475.428\ (\Delta P\rho)^{1/2}$$

DESCRIPTION OF FUEL-FLOW SYSTEM.

The fuel-flow system utilizied during the NAFEC light-aircraft piston engine emission tests incorporated rotameters, turboflow meters, and a burette. The high-flow section incorporated a rotameter in series with a high-flow turbometer, while the low-flow section incorporated a low-flow turbometer in series with a burette. The high-flow system was capable of measuring fuel flows from 50 lb/h up to 300 lb/h with an estimated tolerance of ±1.0 percent. The low-flow system was capable of flow measurements ranging from 0-50 lb/h with an

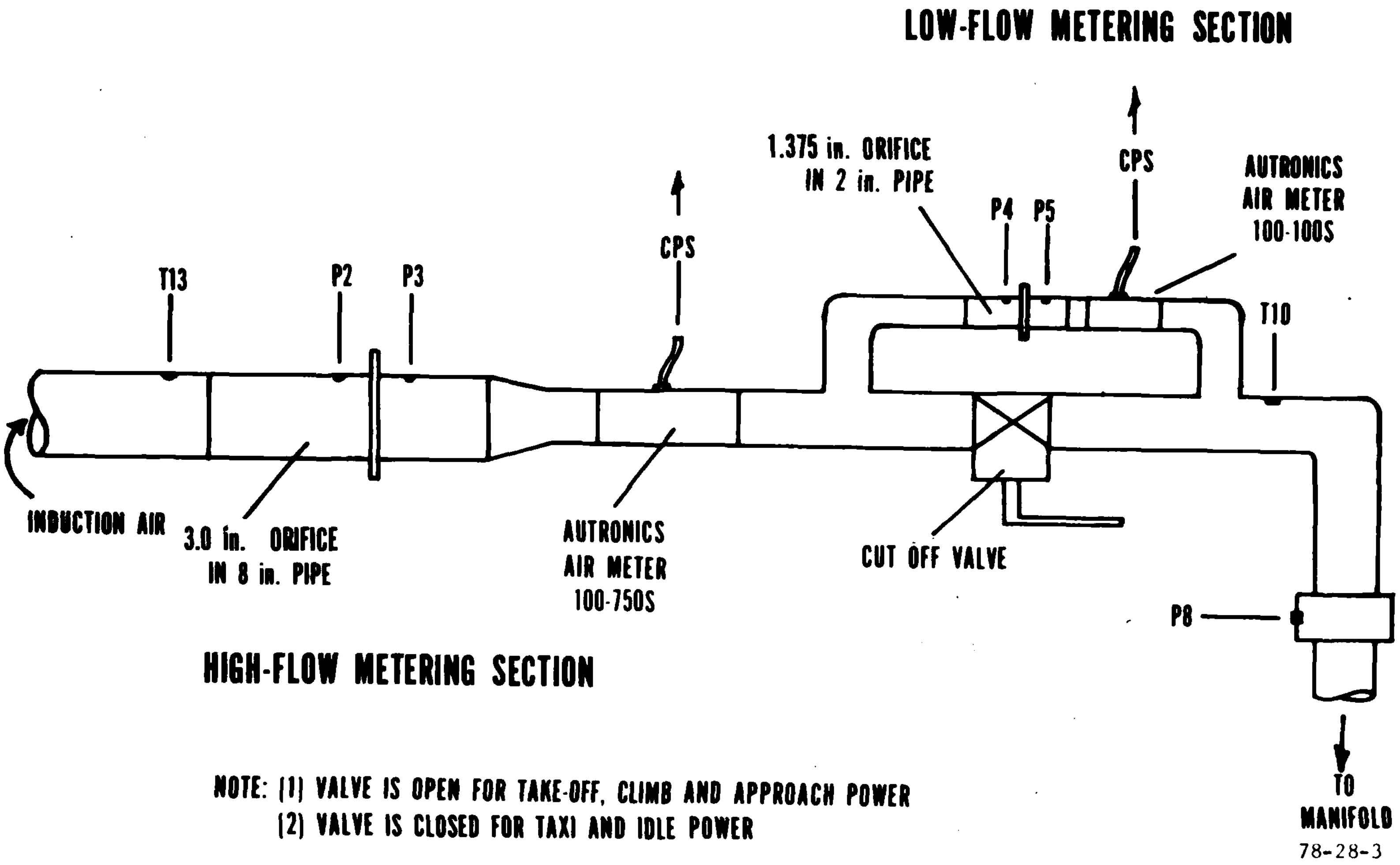


FIGURE 3. NAFEC AIR INDUCTION (AIRFLOW MEASUREMENT) SYSTEM FOR LIGHT-AIRCRAFT PISTON ENGINE EMISSION TESTS

estimated tolerance of ±2.0 percent. Figure 4 illustrates the NAFEC fuel flow system in schematic form.

DESCRIPTION OF COOLING AIR SYSTEM.

The NAFEC piston engine test facility also incorporated a system which provided cooling air (see figure 1) to the engine cylinders. The engine mounted in the test stand was enclosed in a simulated nacelle, and cooling air was provided to this enclosure from an external source. The cooling air temperature was maintained within ±10° F of the induction air supply temperature for any specified set of test conditions. This not only minimized variations in temperature but also minimized variations in the specific weight of air for all test conditions. All of the basic cooling air tests conducted with the O-320/IO-320-DIAD engines (take-off, climb, and approach modes (see appendix C and D) were conducted with differential cooling air pressures of 3.0 inH_2O.

DESCRIPTION OF TEST PROCEDURES AND EPA STANDARDS.

The data presented in this report were measured while conducting tests in accordance with specific landing and takeoff cycles (LTO) and by modal leanout tests. The basic EPA LTO cycle is defined in table 2.

The FAA/NAFEC contract and in-house test programs utilized an LTO cycle which was a modification of the table 2 test cycle. Table 3 defines this modified LTO cycle which was used to evaluate the total full rich emission characteristics of light-aircraft piston engines.

TABLE 2. EPA FIVE-MODE LTO CYCLE

Mode No.	Mode Name	Time-In-Mode (Min.)	Power (%)	Engine Speed (%)
1	Taxi/idle (out)	12.0	*	*
2	Takeoff	0.3	100	100
3	Climb	5.0	75-100	*
4	Approach	6.0	40	*
5	Taxi/idle (in)	4.0	*	*

*Manufacturer's Recommended

TABLE 3. FAA/NAFEC SEVEN-MODE LTO CYCLE

Mode No.	Mode Name	Time-In-Mode (Min.)	Power (%)	Engine Speed (%)
1	Idle (out)	1.0	*	*
2	Taxi (out)	11.0	*	*
3	Takeoff	0.3	100	100
4	Climb	5.0	80	*
5	Approach	6.0	40	*
6	Taxi (in)	3.0	*	*
7	Idle (in)	1.0	*	*

*Manufacturer's Recommended

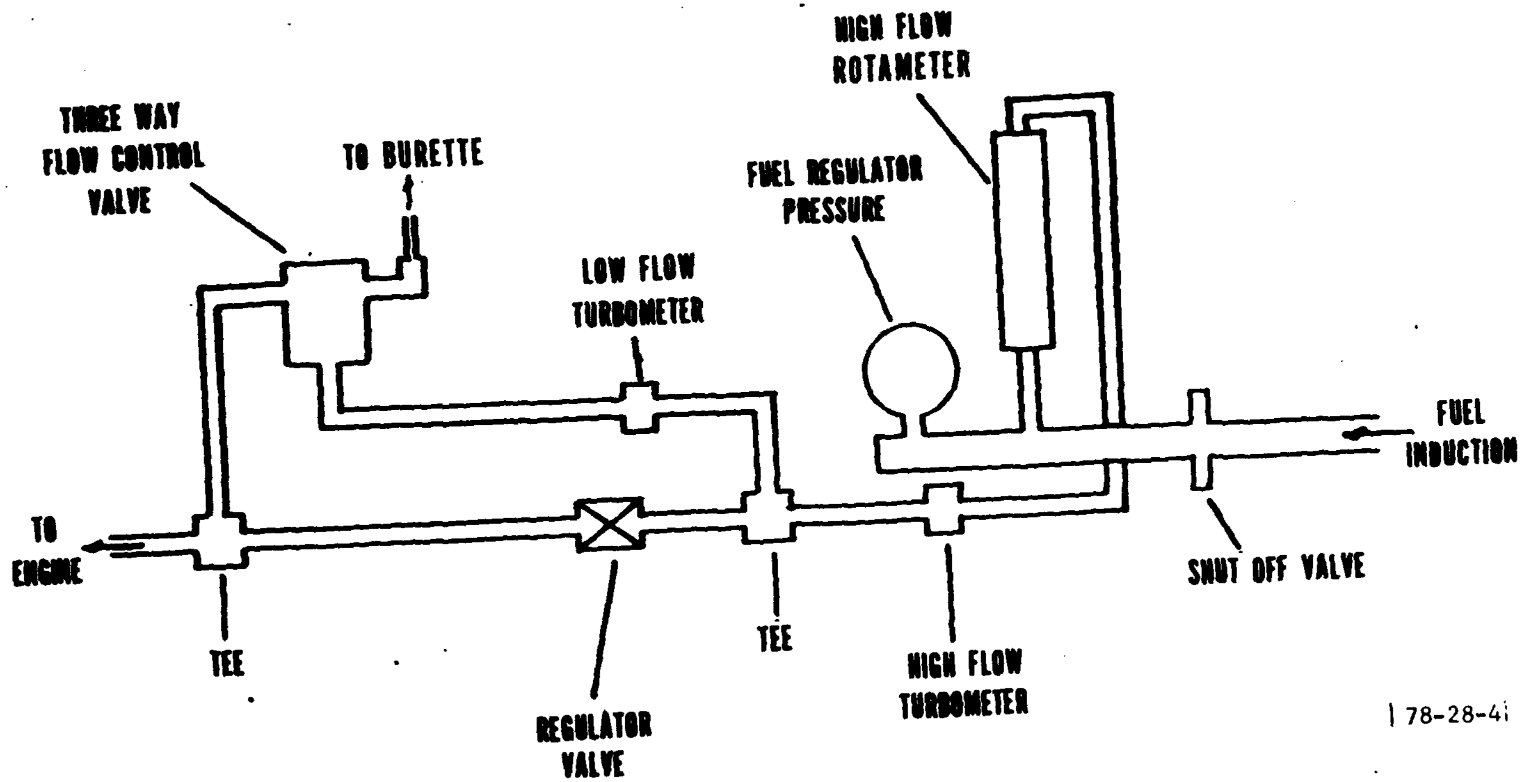


FIGURE 4. NAFEC FUEL-FLOW SYSTEM FOR LIGHT-AIRCRAFT PISTON ENGINE EMISSION TESTS

An additional assessment of the test data clearly indicates that further evaluations of the general aviation piston exhaust emission must be analyzed with the climb mode emissions at 100-percent and 75-percent power setting (tables 4 and 5). This would then provide the basis for a complete evaluation of test data and permit a total assessment of the proposed EPA standard based on LTO cyclic tolerances.

TABLE 4. MAXIMUM FIVE-MODE LTO CYCLE

Mode No.	Mode Name	Time-In-Mode (Min.)	Power (%)	Engine Speed (%)
1	Taxi (out)	12.0	*	*
2	Takeoff	0.3	100	100
3	Climb	5.0	100	100
4	Approach	6.0	40	*
5	Taxi (in)	4.0	*	*

*Manufacturer's Recommended

TABLE 5. MINIMUM FIVE-MODE LTO CYCLE

Mode No.	Mode Name	Time-In-Mode (Min)	Power (%)	Engine Speed (%)
1	Taxi (out)	12.0	*	*
2	Takeoff	0.3	100	100
3	Climb	5.0	75	*
4	Approach	6.0	40	*
5	Taxi (in)	4.0	*	*

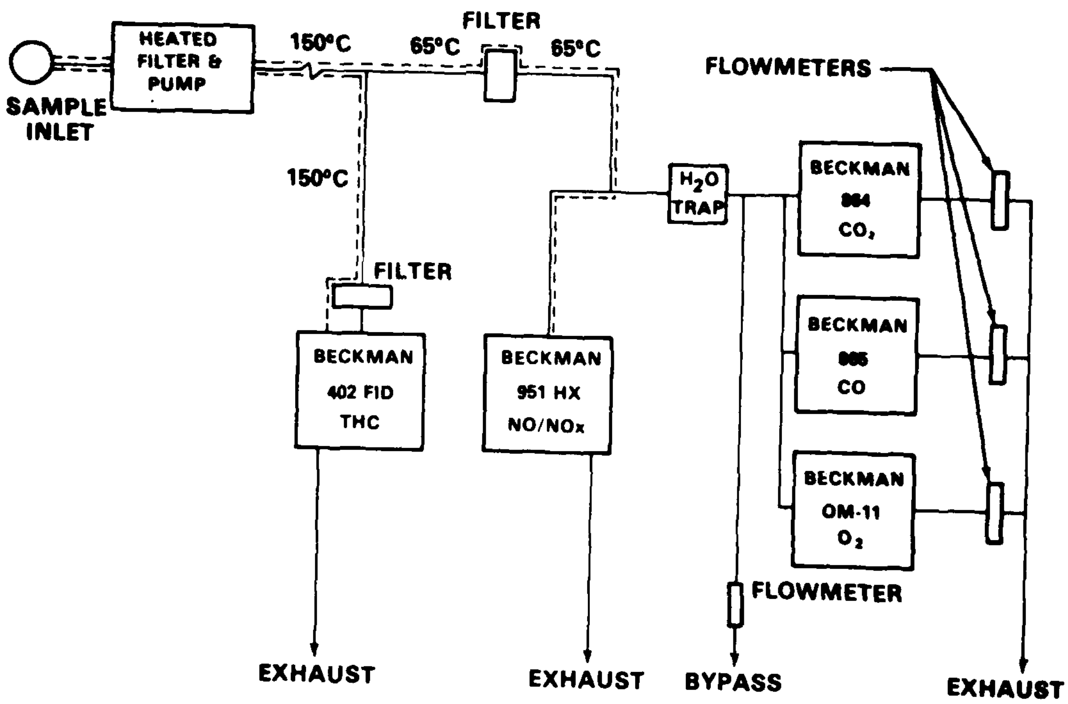
*Manufacturer's Recommended

The EPA Standards (reference 1) that were evaluated during this program were:

Carbon Monixide (CO)—0.042 lb/cycle/rated BHP
Unburned Hydrocarbon (HC)—0.0019 lb/cycle/rated BHP
Oxides of Nitrogen (NO_x)—0.0015 lb/cycle/rated BHP

DESCRIPTION OF EMISSIONS MEASUREMENT SYSTEM (REFERENCE 3).

EMISSION ANALYZERS. The instrumentation used to monitor the exhaust emissions from general aviation piston engines was basically the same as that recommended by EPA, but with a number of modifications and additions to enhance the reliability and accuracy of the system. A schematic of the emissions measurement system is shown in figure 5.



- CARBON DIOXIDE – CO_2
  - NONDISPERSIVE INFRARED (NDIR)
  - RANGE 0 20%
  - REPEATABILITY · 0 2% CO_2
- CARBON MONOXIDE – CO
  - NDIR
  - RANGE 0-20%
  - REPEATABILITY · 0 2% CO
- TOTAL HYDROCARBONS – THC
  - FLAME IONIZATION DETECTOR (FID)
  - RANGE 0-150,000 ppm_c
  - MINIMUM SENSITIVITY 1 5 ppm_c
  - LINEAR TO 150,000 ppm_c

- **OXIDES OF NITROGEN – NO_X**
  - CHEMILUMINESCENT (CL)
  - RANGE 0-10,000 ppm
  - MINIMUM SENSITIVITY 0.1 ppm
- **OXYGEN – O_2**
  - POLARAGRAPHIC
  - RANGE 0-100%
  - REPEATABILITY 0.1% O_2
  - RESPONSE 200 ms

FIGURE 5. SCHEMATIC OF EMISSIONS MEASUREMENT SYSTEMS AND MEASUREMENTS CHARACTERISTICS

EMISSION INSTRUMENTATION ACCURACY/MODIFICATION. The basic analysis instrumentation utilized for this system is explained in the following paragraphs.

Carbon Dioxide. The carbon dioxide (CO_2) subsystem is constructed around a Beckman model 864-23-2-4 nondispersive infrared analyzer (NDIR). This analyzer has a specific repeatability of ±1 percent of full scale for each operating range. The calibration ranges on this particular unit are: Range 1, 0 to 20 percent; Range 3, 0 to 5 percent. Stated accuracy for each range is, ±0.2 and ±0.05 percent, respectively.

Carbon Monoxide. The subsystem used to measure carbon monoxide (CO) is constructed around a Beckman model 865-X-4-4-4 NDIR. This analyzer has a specified repeatability of ±1 percent of full scale for ranges 1 and 2 and ±2 percent of full scale for range 3.

Range 1 has been calibrated for 0 to 20 percent by volume, range 2 for 0 to 1,000 parts per million (ppm) and range 3 for 0 to 100 ppm. The wide-range capability of this analyzer is made possible by using stacked sample cells which in effect give this analyzer six usable ranges when completely calibrated.

Effects of interfering gases, such as CO_2 and water vapor, were determined and reported by the factory. Interferences from 10 percent CO_2 were determined to be 12 ppm equivalent CO, and interferences from 4 percent water vapor were determined to be 6 ppm CO equivalent. Even though the interference from water vapor is negligible, a condenser is used in the CO/CO_2 subsystem to eliminate condensed water in the lines, analyzers, and flowmeters. This condensation would have decreased analyzer sensitivity and necessitated more frequent maintenance if it had been eliminated.

Total Hydrocarbons. The system that is used to measure total hydrocarbons is a modified Beckman model 402 heated flame ionization detector. This analyzer has a full-scale sensitivity that is adjustable to 150,000 ppm carbon with intermediate range multipliers 0.5, 0.1, 0.05, 0.01, 0.005, and 0.001 times full scale.

Repeatability for this analyzer is specified to be ±1 percent of full scale for each range. In addition, this modified analyzer is linear to the full-scale limit of 150,000 ppm carbon when properly adjusted. The two major modifications which were made to this analyzer were the installation of a very fine metering value in the sample capillary tube, and the installation of an accurate pressure transducer and digital readout to monitor sample pressure. Both of these modifications were necessary because of the extreme pressure sensitivity of the analyzer (figures 6 through 8). Correct instrument response depends on the amount of sample passing through a capillary tube; as a result, if there is too high a sample flow, the analyzer response becomes nonlinear when a high concentration gas is encountered. Sample flow may be controlled by varying the pressure on this capillary or increasing the length of the capillary. On this analyzer, linearity to 50,000-ppm carbon was obtained by reducing the sample pressure to 1.5 pounds per square inch gauge (psig). However, the need

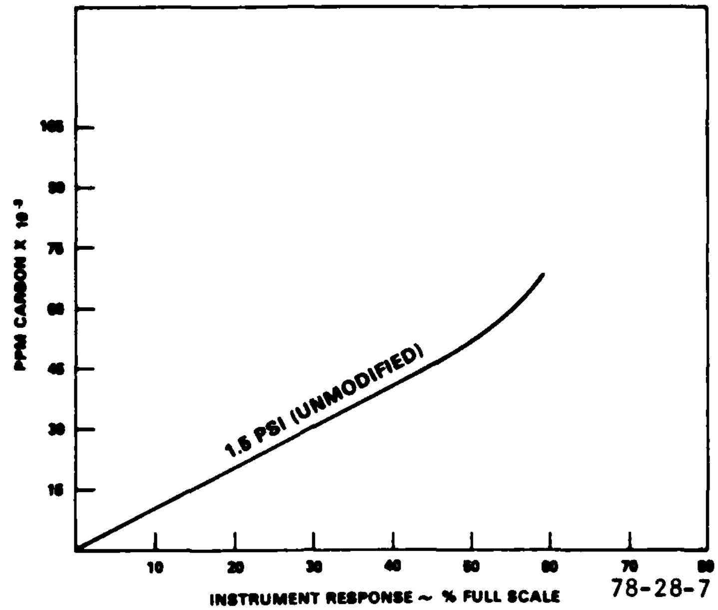


FIGURE 6. BECKMAN MODEL 402 THC ANALYZER (1.5 PSI UNMODIFIED)

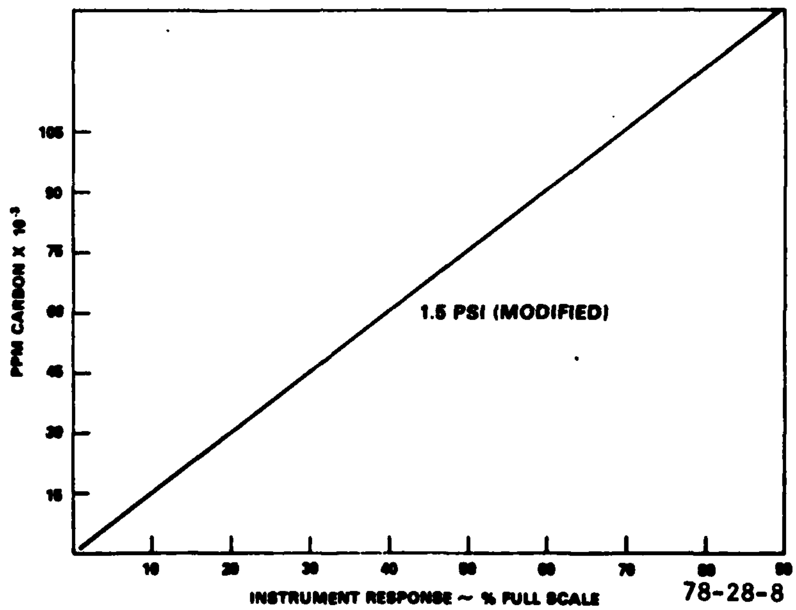


FIGURE 7. BECKMAN MODEL 402 THC ANALYZER (1.5 PSI MODIFIED)

for linearity to 120,000-ppm carbon was anticipated. Further reduction of the sample pressure increased the noise level of the analyzer to an unacceptable level. In order to reduce the flow through the capillary without using a lower pressure, either the length or the resistance of the capillary had to be increased. The standard modification for this analyzer in order to limit flow is the installation of an additional length of capillary tubing. This procedure requires trial and error determination of proper capillary length and is a permanent modification that limits sensitivity at low hydrocarbon levels. By installing a metering valve in the capillary, flow could be selectively set at either low flow for linearity at high concentrations or high flow for greater sensitivity at low concentrations. Installation time was reduced by eliminating the cut-and-try procedure for determining capillary length.

The addition of a sensitive pressure transducer and digital readout to monitor sample pressure was needed since the pressure regulator and gauge supplied with the analyzer would not maintain the pressure setting accurately at low pressures. Using the digital pressure readout, the sample pressure could be monitored and easily maintained to within 0.05 inH_2O.

Oxides of Nitrogen. Oxides of nitrogen (NO_x) are measured by a modified Beckman model 951H atmospheric pressure, heated, chemilluminescent analyzer (CL). This analyzer has a full-scale range of 10,000 ppm with six intermediate ranges. Nominal minimum sensitivity is 0.1 ppm on the 10 ppm full-scale range.

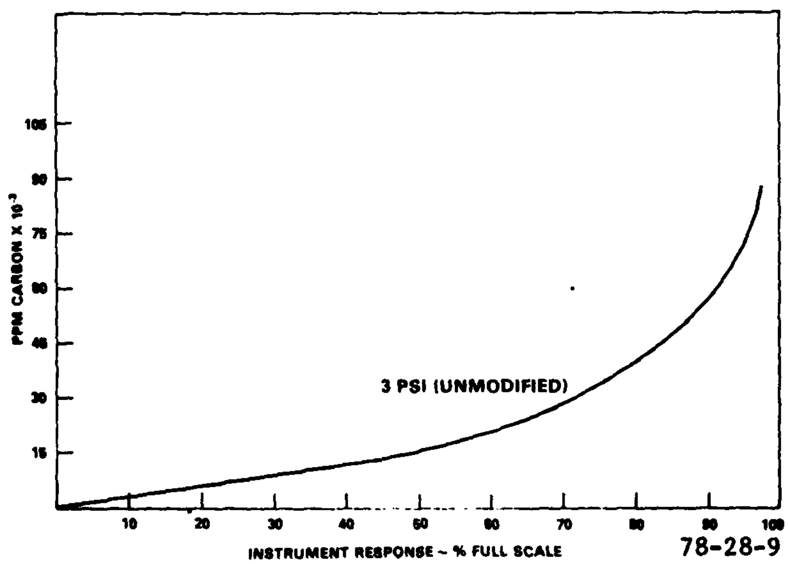


FIGURE 8. BECKMAN MODEL 402 THC ANALYZER (3 PSI UNMODIFIED)

The atmospheric pressure analyzer was chosen because of its simplicity, ease of maintenance, and compactness. Anticipated water vapor problems in the atmospheric pressure unit were to be handled by the heating of the internal sample train. Interference from CO_2 quenching, common in the atmospheric pressure type CL analyzer, was checked and found to be nonexistent.

A series of major modifications were performed by the manufacturer on this analyzer to insure compliance with specifications. One such modification was installed in order to maintain the temperature of the sample stream above the dew point of the sample gas. Originally this analyzer was specified to maintain a temperature of 140° F at all points in contact with the sample. After a survey of the 951H analyzers in use on FAA projects, it was determined that this temperature was not being achieved because the method used to heat the components was inadequate. A recommendation was made to the manufacturer to install a positive method of heating the sample tube compartment and reaction chamber that would be thermostatically controlled. In time, the modification was made, and this problem was eliminated. Increasing the temperature of the internal sample components eliminated the condensed water problem; however, the elevated temperature caused an instability in the photomultiplier tube output. Another recommendation was made to thermostatically control the temperature of this tube. This was accomplished by installing an electronic cooling jacket designed to maintain the photomultiplier tube at a constant temperature below the internal case temperature.

A further modification required was the addition of a flow control valve to adjust and balance the flow rate through the NO and NO_x legs. This valve replaced a restrictor clamp that was used by the manufacturer to set the NO to NO_x flow balance. The problem that was encountered with this clamp was that it was not a positive method of adjusting the restriction on the capillary. The clamp compression was affected by the flexible material on which the clamp was mounted and the variable flexibility of the teflon® capillary as it was heated. This caused the restriction on the capillary to change with time and caused permanent deformation of the capillary allowing only an adjustment that would increase the restriction.

Oxygen Measurement. Oxygen (O_2) was measured by a Beckman model OM-11 oxygen analyzer. This analyzer uses a polarographic type sensor unit to measure oxygen concentration. An advanced sensor and amplification system combine to give an extremely fast response and high accuracy. Specified response for 90 percent of final reading is less than 200 milliseconds (ms) with an accuracy of less than ± 0.1-percent O_2. The range of this unit is a fixed 0 to 100 percent O_2 concentration.

EMISSIONS INSTRUMENTATION MODIFICATION STATUS DURING THE TESTING OF THE 0-320/IO-320-DIAD ENGINE. The tests conducted with the Avco Lycoming 0-320/IO-320-DIAD engine utilized all of the above noted instrumentation and the latest modifications to this instrumentation. The OM-11 O_2 analyzer and the latest prototype 951H NO_x analyzer were both in use. All of the emissions and exhaust constituent-measuring instrumentation/analyzers incorporated the latest specified modifications described in this report.

DESCRIPTION OF SAMPLE HANDLING SYSTEM.

Exhaust samples are transported to the analysis instrumentation under pressure through a 35-foot-long, 3/8-inch O.D., heated, stainless steel sample line. The gas is first filtered and then pumped through this line by a heated Metal Bellows model MB-158 high temperature stainless steel sample pump. The pump, filter, and line are maintained at a temperature of 300° $\pm$4° F to prevent condensation of water vapor and hydrocarbons. At the instrument console, the sample is split to feed the hydrocarbon, oxides of nitrogen, and $CO/CO_2/O_2$ subsystems which require different temperature conditioning. The sample gas to the total hydrocarbon subsystem is maintained at 300° F while the temperature of remaining sample gas to the NO_x and $CO/CO_2/O_2$ system is allowed to drop to 150° F. Gas routed to the oxides of nitrogen subsystem is then maintained at 150° F, while the gas to the $CO/CO_2/O_2$ subsystem is passed through a 32° F condenser to remove any water vapor present in the sample. Flow rates to each analyzer are controlled by a fine-metering valve and are maintained at predetermined values to minimize sample transport and system response time. Flow is monitored at the exhaust of each analyzer by three 15-centimeter (cm) rotameters. Two bypasses are incorporated into the system to keep sample transport time through the lines and condenser to a minimum without causing adverse pressure effects in the analyzers.

DESCRIPTION OF FILTRATION SYSTEM.

Particulates are removed from the sample at three locations in the system, thereby minimizing downtime due to contaminated sample lines and analyzers (figure 5). Upstream of the main sample pump is a heated clamshell-type stainless steel filter body fitted with a Whatman GF/C glass fiber paper filter element capable of retaining particles in the 0.1 micron range. A similar filter is located in the total hydrocarbon analyzer upstream of the sample capillary. A Mine Safety Appliances (MSA) type H ultra filter capable of retaining 0.3 micron particles is located at the inlet to the oxides of nitrogen and $CO/CO_2/O_2$ subsystems.

COMPUTATION PROCEDURES.

The calculations required to convert exhaust emission measurements into mass emissions are the subject of this section.

Exhaust emission tests were designed to measure CO_2, CO, unburned hydrocarbons (HC), NO_x, and exhaust excess O_2 concentrations in percent or ppm by volume. Mass emissions were determined through calculations utilizing the data obtained during the simulation of the aircraft LTO cycle and from modal lean-out data.

COMBUSTION EQUATION. The basic combustion equation can be expressed very simply:

Fuel + Air = Exhaust Constituents

An initial examination of the problem requires the following simplifying assumptions:

1. The fuel consists solely of compounds of carbon and hydrogen.

2. The air is a mixture of oxygen and inert nitrogen in the volumetric ratio of 3.764 parts apparent nitrogen to 1.0 part oxygen (see appendix B for additional details).

3. If a stoichiometric combustion process exists, the fuel and air are supplied in chemically correct proportions.

4. The fuel (which consists usually of a complex mixture of hydrocarbons) can be represented by a single hydrocarbon having the same carbon-hydrogen ratio and molecular weight as the fuel; usually C_8H_{17} as an average fuel.

Applying the above assumptions for stoichiometric conditions, a useful general reaction equation for hydrocarbon fuel is:

$$M_f C_8H_{17} + M_a\ (O_2 + 3.764N_2 + M_w H_2O) \quad M_1 CO_2 + M_3 H_2O + M_5 N_2 \qquad (1)$$

(References 4 and 5)

Where
M_f = Moles of Fuel
M_a = Moles of Air or Oxygen
M_1 = Moles of Carbon Dioxide (CO_2)
M_3 = Moles of Condensed Water (H_2O)
M_5 = Moles of Nitrogen (N_2) - Exhaust
$3.764M_a$ = Moles of Nitrogen (N_2) - In Air
M_aM_w = Moles of Humidity (H_2O) - In Air

The above equation is applicable to dry air when M_w is equal to zero.

From equation (1), and assuming dry air with one mole of fuel (M_f=1.0), the stoichiometric fuel-air ratio may be expressed as:

$$(F/A)_s = \frac{\text{Wt. Fuel}}{\text{Wt. Air Required}} = \frac{12.011\ (8) + 1.008\ (17)}{12.25\ [(32.000) + 3.764(28.161)]} \qquad (2)$$

$$(F/A)_s = \frac{113.224}{12.25(137.998)} = 0.067$$

The mass carbon-hydrogen ratio of the fuel may be expressed as follows:

$$C/H = \frac{12.011(8)}{1.008(17)} = \frac{96.088}{17.136} = 5.607 \qquad (3)$$

The atomic hydrogen-carbon ratio is:

$$17/8 = 2.125 \qquad (4)$$

The stoichiometric fuel-air ratio may be expressed as a function of the mass carbon-hydrogen ratio of the fuel. The derivation of this equation is presented in reference 4.

$$(F/A)_s = \frac{C/H + 1}{11.5(C/H+3)} \qquad (5)$$

$(F/A)_s$ = 0.067 for a mass carbon-hydrogen ratio of 5.607

With rich (excess fuel) mixtures, which are typical for general aviation piston engines, some of the chemical energy will not be liberated because there is not enough air to permit complete oxidation of the fuel. Combustion under such conditions is an involved process. By making certain simplifying assumptions based on test results, the effect of rich mixtures may be calculated with reasonable accuracy.

For rich (excess fuel) mixtures, equation (1) will now be rewritten to express the effects of incomplete combustion:

$$M_fC_8H_{17} + M_a(O_2 + 3.764N_2 + M_wH_2O) \rightarrow M_1CO_2 + M_2CO + M_3H_2O + M_4H_2 +$$

$$M_5N_2 + M_6NO + M_7CH_4 + M_8O_2 + M_9C \qquad (6)$$

Since only a limited number of the exhaust constituents were measured during the testing of general aviation piston engines, the above equation can only be solved by applying certain expeditious assumptions and empirical data.

An important requirement was the accurate measurement of air and fuel flows. These parameters provide the data for determining engine mass flow (W_m), and with the aid of figure 9 (developed from reference 6), it is a simple computation to calculate the total moles (M_{tp}) of exhaust products being expelled by general aviation piston engines.

$$(M_{tp}) = W_m \text{ (engine mass flow) } \div \text{ (exh. mol. wt)} \qquad (7)$$

Since the unburned hydrocarbons (HC) and oxides of nitrogen (NO_x) are measured wet, it becomes a very simple matter to compute the moles of HC and NO_x that are produced by light-aircraft piston engines.

$$M_7 \text{ (Moles of HC)} = (\text{ppm} \div 10^6) \times M_{tp} \qquad (8)$$

$$M_6 \text{ (Moles of } NO_x) = (\text{ppm} \div 10^6) \times M_{tp} \qquad (9)$$

If the dry products (M_{dp}) of combustion are separated from the total exhaust products (M_{tp}), it is possible to develop a partial solution for five of the products specified in equation 6.

This can be accomplished as follows:

The summation of the mole fractions $(MF)_d$ for dry products is:

$$m_1 + m_2 + m_4 + m_5 + m_8 = 1.0000 \qquad (10)$$

$m_1 = MF(CO_2) = \%CO_2$ (measured dry), expressed as a fraction

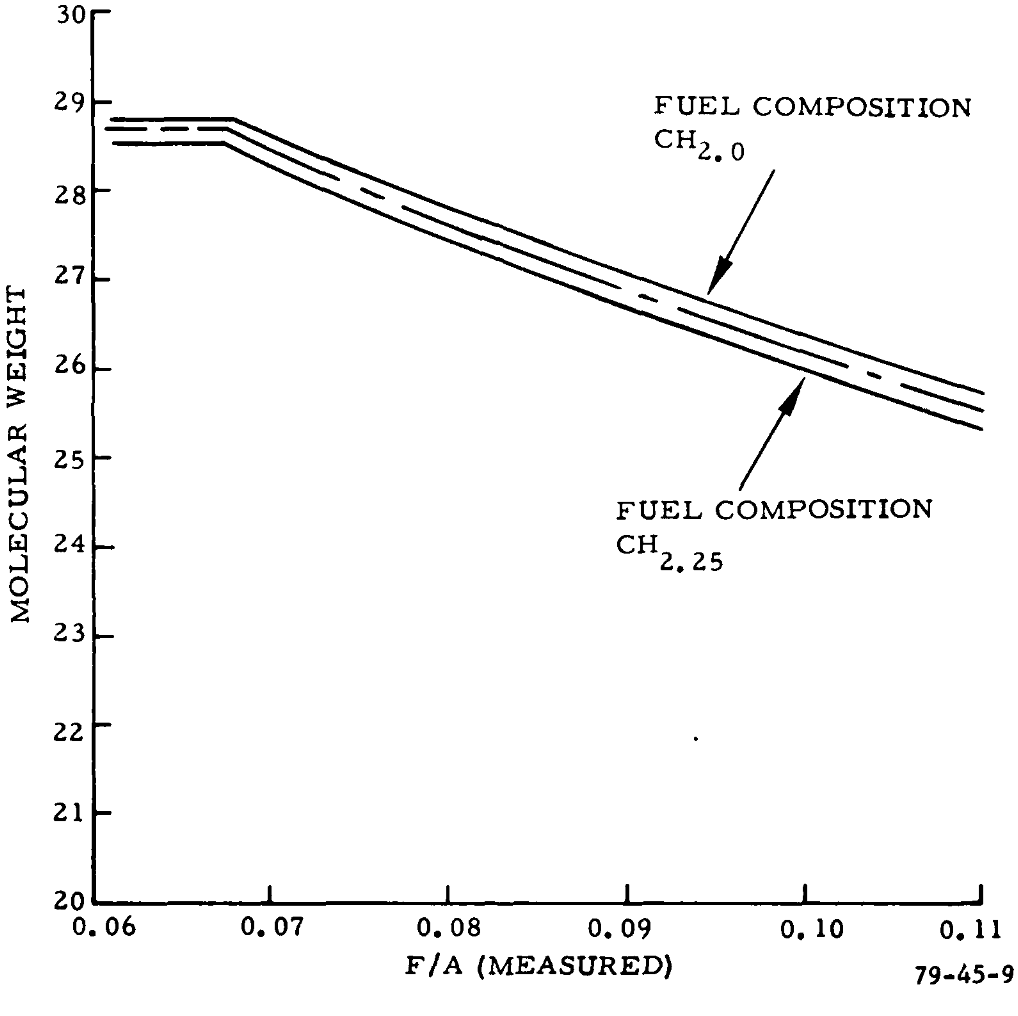


FIGURE 9. EXHAUST GAS MOLECULAR WEIGHTS

$m_2 = MF(CO) = \%CO$ (measured dry), expressed as a fraction

$m_4 = MF(H_2) = K_4\ (\%CO)$ (see figure 10, also references 4, 5, and 6), expressed as a fraction

$m_8 = MF(O_2) = \%O_2$ (measured dry), expressed as a fraction

$$m_5 = 1.0000 - (m_1 + m_2 + m_4 + m_8) = \%N_2 \text{ (dry), expressed as a fraction} \quad (11)$$

Utilizing the nitrogen balance equation, it is now possible to determine the moles of nitrogen that are being exhausted from the engine.

$$M_5 = 3.764M_a - (M_6 \div 2);\ M_6 = \text{moles (NO)} \quad (12)$$

The moles of exhaust dry products (M_{dp}) may now be determined by dividing equation 12 by equation 11.

$$M_{dp} = M_5 \div M_5 \quad (13)$$

Using all the information available from equations (7), (8), (9), (10), (11), (12), and (13), it is now possible to determine the molar quantities for seven exhaust products specified in equation 6.

$$\text{Moles } (CO_2) = M_1 = m_1 \times M_{dp} \quad (14)$$

$$\text{Moles } (CO) = M_2 = m_2 \times M_{dp} \quad (15)$$

$$\text{Moles } (H_2) = M_4 = m_4 \times M_{dp} \quad (16)$$

$$\text{Moles } (N_2) = M_5 = m_5 \times M_{dp} \quad (17)$$

$$\text{Moles } (O_2) = M_8 = m_8 \times M_{dp} \quad (18)$$

$$\text{Moles } (CH_4) = M_7 = (\text{ppm} \div 10^6) \times M_{tp} \quad (19)$$

$$\text{Moles } (NO) = M_6 = (\text{ppm} \div 10^6) \times M_{tp} \quad (20)$$

To determine M_3 (moles of condensed H_2O), it is now appropriate to apply the oxygen balance equation.

$$M_3 = M_a\ (2 + M_w) - (2M_1 + M_2 + M_6 + 2M_8) = \text{Moles } (H_2O) \quad (21)$$

The remaining constituent specified in equation 6 may now be determined from the carbon balance equation 22.

$$M_9 = 8M_f - (M_1 + M_2 + M_7) \quad (22)$$

A check for the total number of exhaust moles (M_{tp}), calculated from equation 9, may now be determined from equation 23.

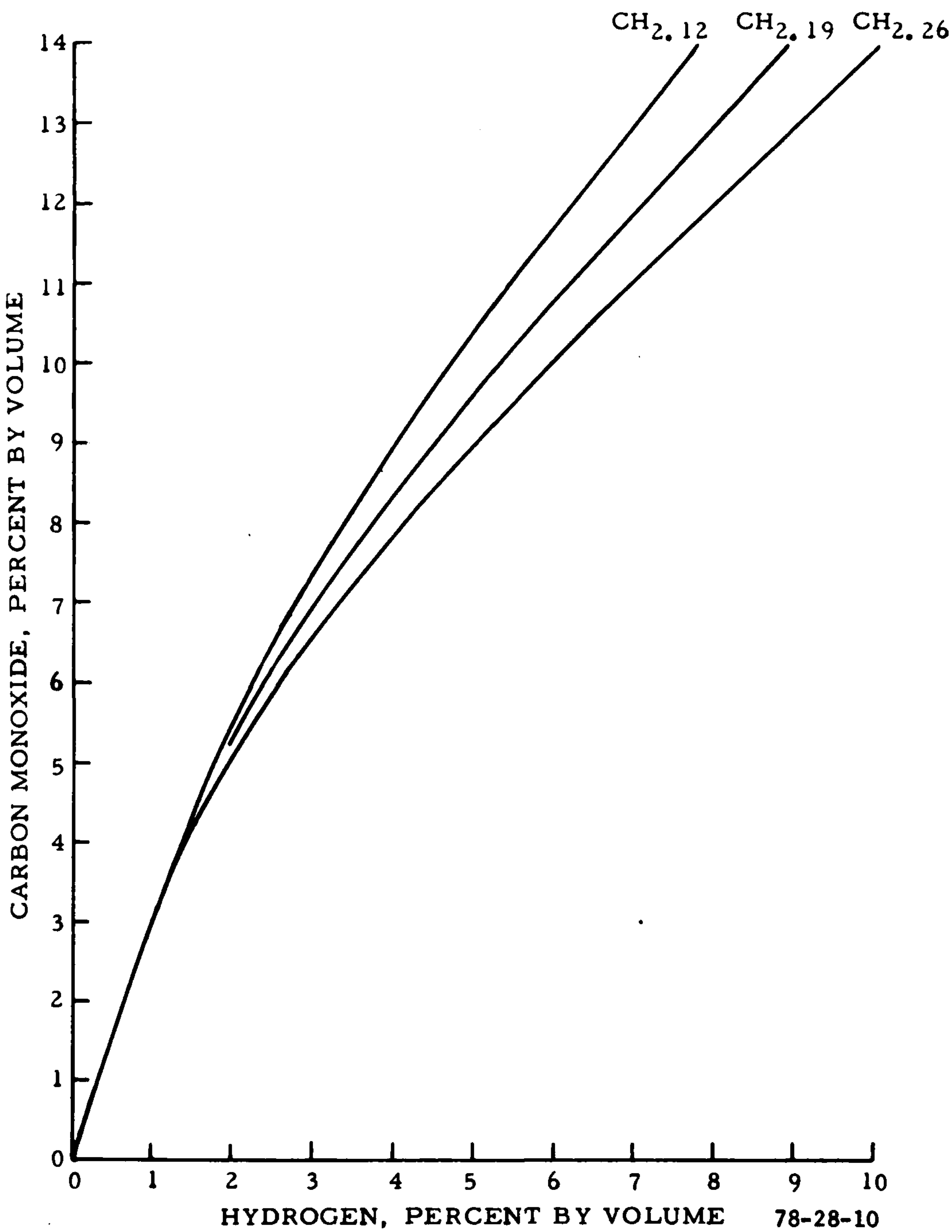


FIGURE 10. RELATION OF CARBON MONOXIDE AND HYDROGEN

$$M_{tp} = M_1 + M_2 + M_3 + M_4 + M_5 + M_6 + M_7 + M_8 + M_9 \qquad (23)$$

$$\dot{m}_1 + \dot{m}_2 + \dot{m}_3 + \dot{m}_4 + \dot{m}_5 + \dot{m}_6 + \dot{m}_7 + \dot{m}_8 + \dot{m}_9 = 1.0000 \qquad (24)$$

$$\dot{m}_1 = MF(CO_2) = M_1 \div M_{tp}$$

$$\dot{m}_2 = MF(CO) = M_2 \div M_{tp}$$

$$\dot{m}_3 = MF(H_2O) = M_3 \div M_{tp}$$

$$\dot{m}_4 = MH(H_2) = M_4 \div M_{tp}$$

$$\dot{m}_5 = MF(N_2) = M_5 \div M_{tp}$$

$$\dot{m}_6 = MH(NO) = M_6 \div M_{tp}$$

$$\dot{m}_7 = MF(CH_4) = M_7 \div M_{tp}$$

$$\dot{m}_8 = MF(O_2) = M_8 \div M_{tp}$$

$$\dot{m}_9 = MF(C) = M_9 \div M_{tp}$$

The exhaust constituent mass flow rates may be computed in the following manner using each exhaust constituents molar constant with the appropriate molecular weight.

$$M_1 \times 44.011 = CO_2 \text{ in lb/h} \qquad (25)$$

$$M_2 \times 28.011 = CO \text{ in lb/h} \qquad (26)$$

$$M_3 \times 18.016 = H_2O \text{ in lb/h} \qquad (27)$$

$$M_4 \times 2.016 = H_2 \text{ in lb/h} \qquad (28)$$

$$M_5 \times 28.161 = N_2 \text{ in lb/h} \qquad (29)$$

$$M_6 \times 30.008 = NO \text{ in lb/h} \qquad (30)$$

$$M_7 \times 16.043 = CH_4 \text{ in lb/h} \qquad (31)$$

$$M_8 \times 32.000 = O_2 \text{ in lb/h} \qquad (32)$$

$$M_9 \times 12.011 = C \text{ in lb/h} \qquad (33)$$

The exhaust fuel flow (W_{fe}), based on exhaust constituents, can now be calculated on a constituent-by-constituent basis as follows:

$$(M_1 + M_2 + M_9) \times 12.011 = \text{lb/h} \qquad (34)$$

$$M_7 \times 16.043 = \text{lb/h} \qquad (35)$$

$$(M_3 - M_aM_w) + M_4 \times 2.016 = \text{lb/h} \tag{36}$$

$$W_{fe} = (34) + (35) + (36) = \text{lb/h} \tag{37}$$

In a similar manner the exhaust airflow (W_{ae}) can also be calculated on a constituent-by-constituent basis:

$$M_1 \times 32.000 = \text{lb/h} \tag{38}$$

$$M_2 \times 16.000 = \text{lb/h} \tag{39}$$

$$(M_3 \times 16.000) + (M_aM_w \times 18.016) = \text{lb/h} \tag{40}$$

$$M_5 \times 28.161 = \text{lb/h} \tag{41}$$

$$M_6 \times 30.008 = \text{lb/h} \tag{42}$$

$$M_8 \times 32.000 = \text{lb/h} \tag{43}$$

$$W_{ae} = \Sigma\ (38) \leftrightarrow (43) = \text{lb/h} \tag{44}$$

Using equations (37) and (44) it is now possible to determine a calculated fuel-air ratio on the basis of total exhaust constituents.

$$(F/A) \text{ calculated} = (37) \div (44) \tag{45}$$

RESULTS

GENERAL COMMENTS.

General aviation piston engine emission tests were conducted to provide the following categories of data:

1. Full-rich (or production fuel schedule) baseline data for each power mode specified in the LTO test cycle.

2. Lean-out data for each power mode specified in the LTO test cycle.

3. Data for each power mode specified in the LTO test cycle utilized cooling air flow, $\Delta P \doteq 3.0$ inH_2O at takeoff, climb, and approach powers.

RESULTS OF BASELINE TESTS (LANDING-TAKEOFF CYCLE EFFECTS).

Based on an analysis of the factors affecting piston engine emissions (time in mode, F/A, ambient conditions, etc.), it can be shown that the mode conditions having the greatest influence on the gross pollutant levels produced by the combustion process are taxi, approach, and

climb when using the LTO cycle defined in tables 3, 4, and 5. The five-mode LTO cycle shows that approximately 99 percent of the total cycle time (27.3-min) is attributed to these three modal conditions. Furthermore, the taxi modes (both out and in) account for slightly less than 59 percent of the total cycle time. The remainder of the time is almost equally apportioned to the approach and climb modes (22 and 18 percent, respectively).

As a result of these time apportionments, it was decided that an investigation and evaluation of the data should be undertaken to determine which mode(s) has the greatest influence on improving general aviation piston engine emissions. The subsequent sections of this report will show the exhaust emissions characteristics for an Avco Lycoming 0-320/IO-320-DIAD engine (S/N889-X) and what improvements are technically feasible within the limits of safe aircraft/engine operational requirements based on sea level propeller test stand evaluations conducted at NAFEC.

The first set of data to be presented and evaluated is the five-mode baseline runs conducted to establish the current production full-rich exhaust emissions characteristics of the 0-320/IO-320-DIAD engine. These are summarized in tabular form in appendices C and D and includes data that were obtained for a range of sea level ambient conditions, specified as follows:

Induction air temperature (T_i)	= 30° F to 115° F
Cooling air temperature (T_c)	= $T_i \pm 10°$ F
Induction air pressure (P_i)	= 29.50 to 31.00 inHgA
Induction air density (ρ)	= 0.0710 to 0.0820 lb/ft^3

Figure 11 shows five-mode baseline data in bargraph form (for nominal sea level standard day conditions). It also compares the total emissions characteristics of the 0-320/IO-320-DIAD engine (current production configuration) with the proposed EPA standards as a function of percent of standard. The data that were utilized to develop figure 11 are tabulated in appendices C and D and are plotted in various forms for analysis and evaluation in these appendices.

RESULTS OF LEAN-OUT TESTS.

In the subsequent sections of this report, it will be shown what improvements can be achieved as a result of making lean-out adjustments to the fuel metering device: (1) taxi mode only, (2) taxi and approach modes combined, and (3) leaning-out the climb mode to "best power" in combination with taxi and approach mode leaning.

EFFECTS OF LEANING-OUT ON CO EMISSIONS. The test data obtained as a result of NAFEC testing the 0-320/IO-320-DIAD have been evaluated on the basis of leaning-out the taxi, approach, and climb modes while continuing the operation of the test engine at the production rich and lean limits in the takeoff mode. The results of leaning-out under this procedure are shown in bargraph form in figures 12, 13 and 14.

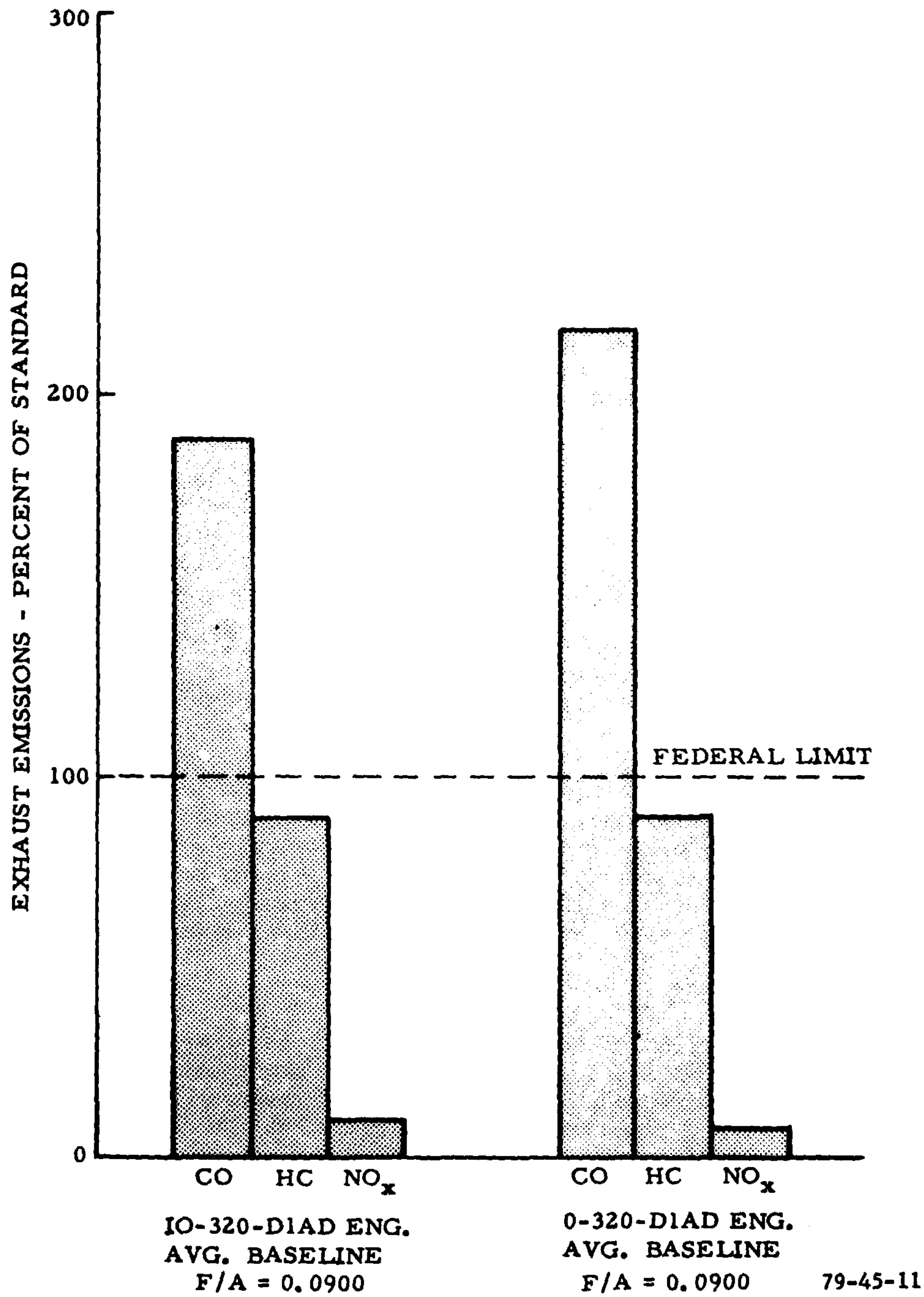


FIGURE 11. TOTAL EMISSIONS CHARACTERISTICS—AVCO LYCOMING IO-320/0-320-DIAD ENGINES OPERATING UNDER NOMINAL SEA LEVEL STANDARD DAY CONDITIONS AND THE SAME AVERAGE, REFERENCE FUEL-AIR RATIO FOR THE TABLE 5 EPA LTO CYCLE

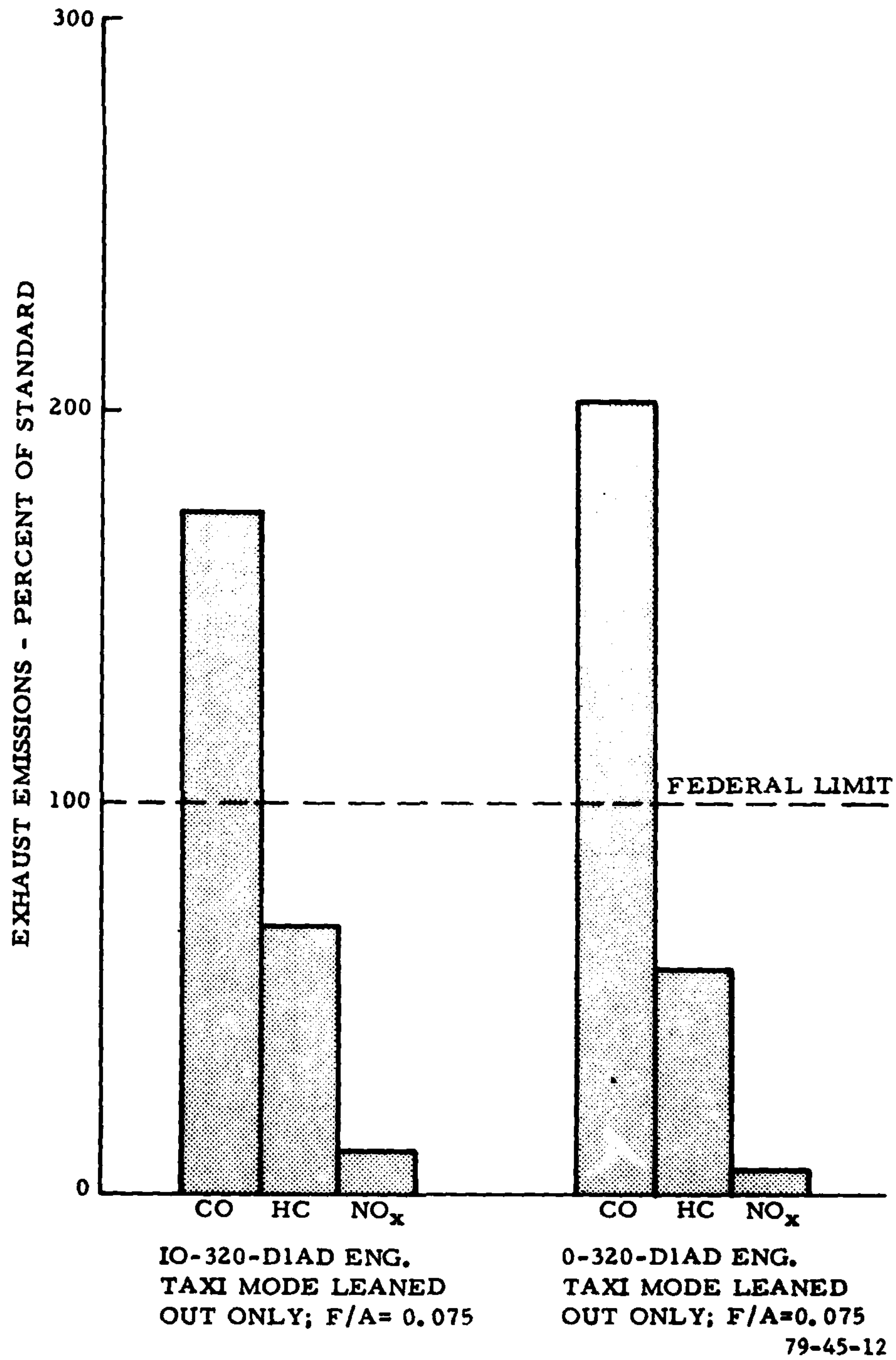


FIGURE 12. TOTAL EMISSIONS CHARACTERISTICS—AVCO LYCOMING IO-320/0-320-DIAD ENGINES OPERATING UNDER NOMINAL SEA LEVEL STANDARD DAY CONDITIONS; TAKEOFF, CLIMB, AND APPROACH MODE F/A's SAME AS FIGURE 11—TABLE 5 EPA LTO CYCLE

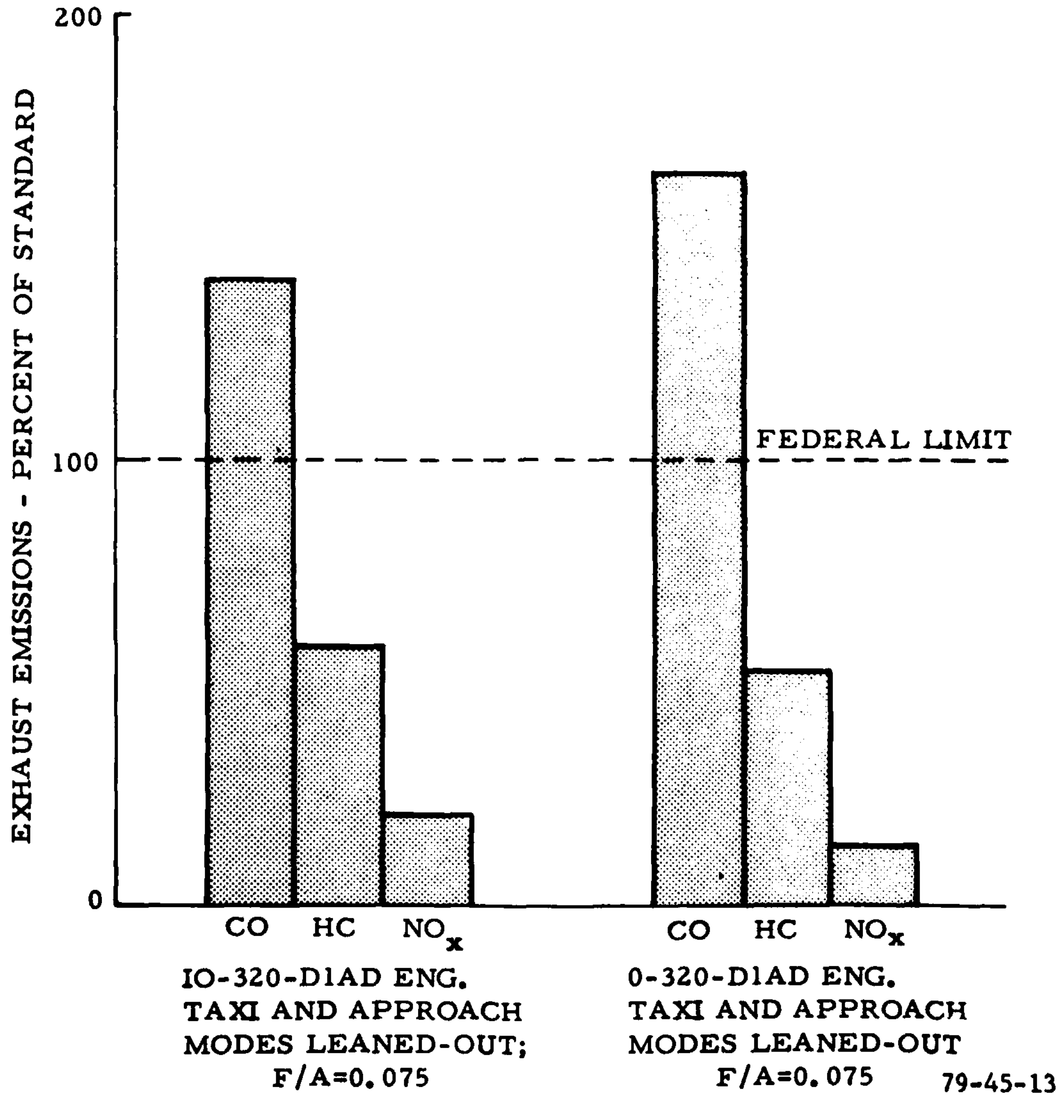


FIGURE 13. TOTAL EMISSIONS CHARACTERISTICS--AVCO LYCOMING IO-320/0-320-DIAD ENGINES OPERATING UNDER NOMINAL SEA LEVEL STANDARD DAY CONDITIONS; TAKEOFF AND CLIMB MODE F/A's SAME AS FIGURE 11--TABLE 5 EPA LTO CYCLE

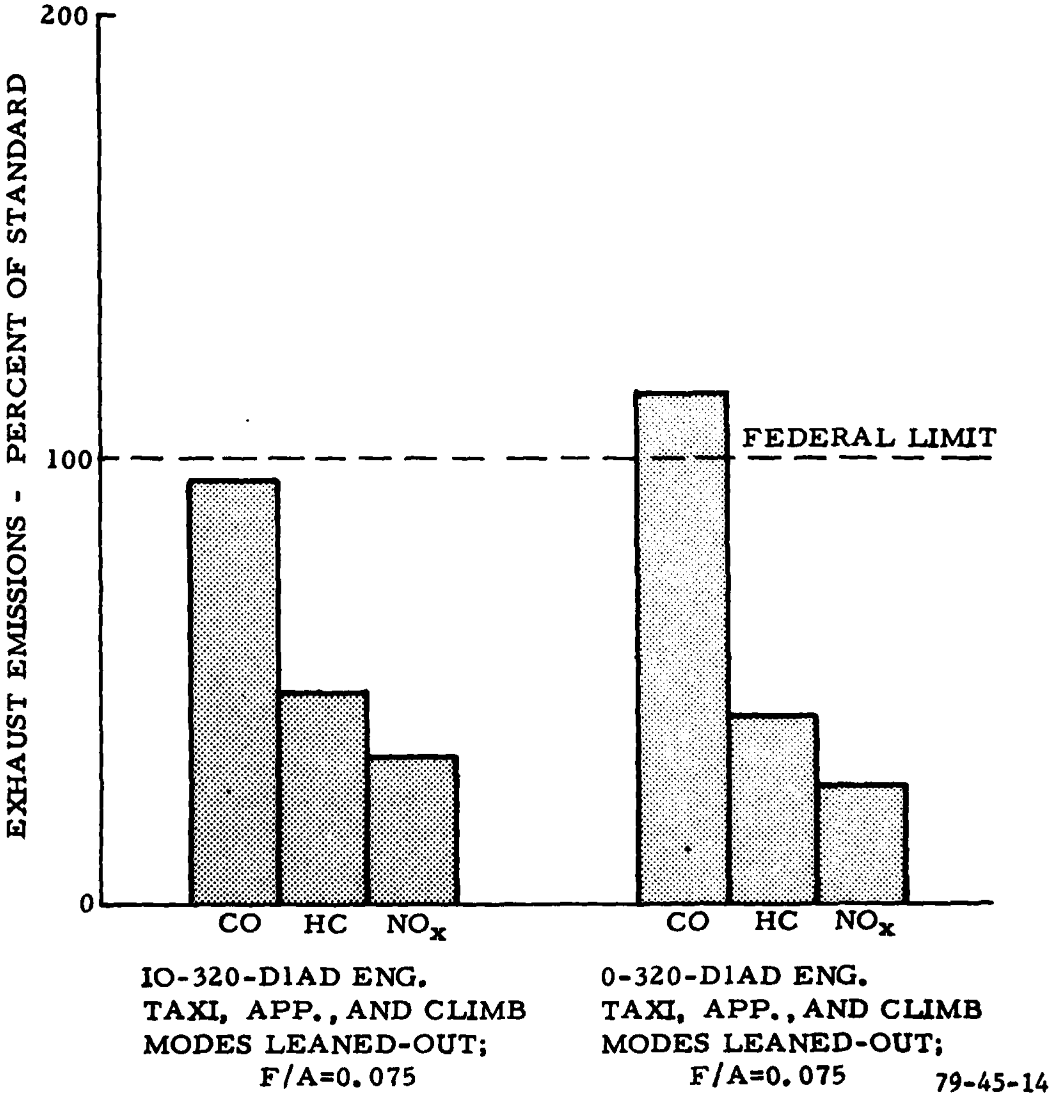


FIGURE 14. TOTAL EMISSIONS CHARACTERISTICS--AVCO LYCOMING IO-320/0-320-D1AD ENGINES OPERATING UNDER NOMINAL SEA LEVEL STANDARD DAY CONDITIONS; TAKEOFF MODE F/A's SAME AS FIGURE 11--TABLE 5 EPA LTO CYCLE

When the taxi modes (out and in) were leaned-out from the production rich or lean limits to a fuel-air ratio of 0.075, but not lower than stoichiometric (F/A = 0.067) (figure 12.) CO emissions are reduced approximately 14-15 percent. However, adjustments to the taxi mode fuel schedule alone are not sufficient to bring the total five-mode LTO cycle CO emission level below the proposed federal standard.

Simultaneously, leaning-out both the taxi and approach modes to fuel-air ratios to 0.075 will result in additional improvements in CO emissions. In the case of operating the engine at production rich limits for takeoff and climb while operating taxi and approach at F/A = 0.075, the total five-mode LTO cycle CO emission level will be reduced approximately 50 percent as shown in figure 13.

Additional improvements in the total five-mode LTO cycle for CO emissions can be achieved, as shown in figure 14, if the engine is adjusted to operate at or near "best power" fuel-air ratios in the climb mode (F/A = 0.075) while operating the approach and taxi modes at F/A = 0.075.

The preceding evaluation of CO emissions characteristics was based on the LTO cycle defined by table 5. However, the EPA five-mode LTO cycle defined by table 2 implies that the climb mode power levels range from 75 to 100 percent. The exhaust emissions produced will be drastically affected. Examination of the measured data produced at NAFEC shows that there is a significant difference in each engine's total LTO cycle emissions output when climbing at 100 percent power compared to climbing at 75-or 80-percent power. This data evaluation also shows that where as a CO limit of 0.042 pounds per cycle per rated brake horsepower may be approximately achievable as described previously by using the LTO cycle defined by table 5; it is <u>not</u> achievable using an LTO cycle defined by table 4. When one considers the following safety considerations: (1) sea level, hot-day takeoff requirements with an aircraft at heavy gross weight and (2) altitude takeoff requirements with an aircraft at heavy gross weight, it would appear that the EPA 0.042 limit for CO is not realistic and cannot be complied with unless engine operational and safety limits are totally ignored. Figures 15 through 18 illustrate the emissions characteristics that would result when operating the engine to the requirements of table 4.

Tables 6 and 7 provide a summary of the NAFEC data which indicates what levels of improvement in CO emissions can be achieved by applying simple fuel management techniques (leaning-out by mixture control manipulations), albeit with drastically reduced margins between actual measured maximum cylinder head temperature (CHT), the maximum CHT limit, and maximum service life limits established by reference 14.

<u>Example</u>: Consider the engine installed in a sea level (SL) propeller stand and operating with cooling air at a ΔP = 3.0 inH_2O and the following critical test conditions:

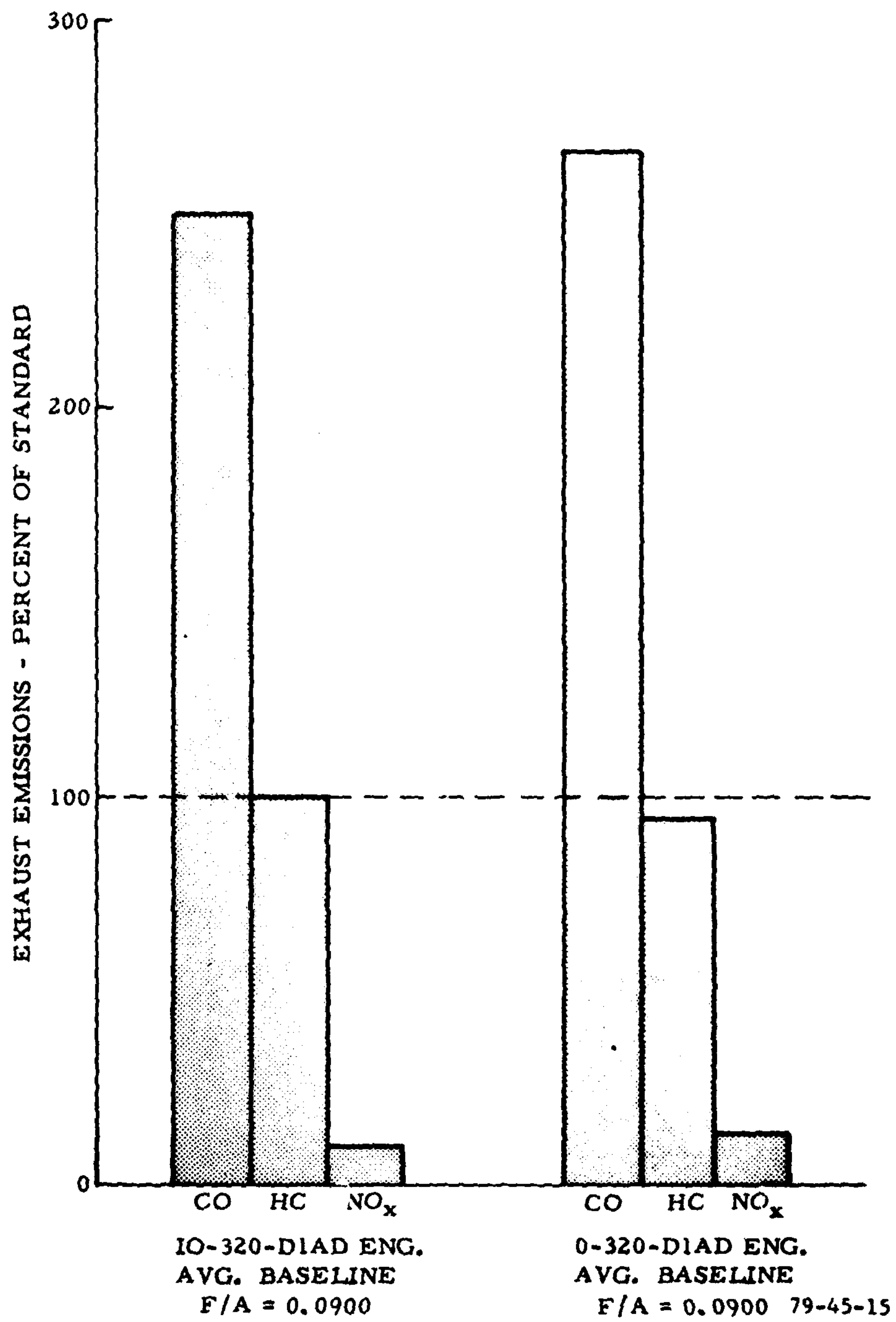


FIGURE 15. TOTAL EMISSIONS CHARACTERISTICS--AVCO LYCOMING IO-320/0-320-DIAD ENGINES OPERATING UNDER NOMINAL SEA LEVEL STANDARD DAY CONDITIONS AND THE SAME AVERAGE, REFERENCE FUEL-AIR RATIO FOR THE TABLE 4 EPA LTO CYCLE

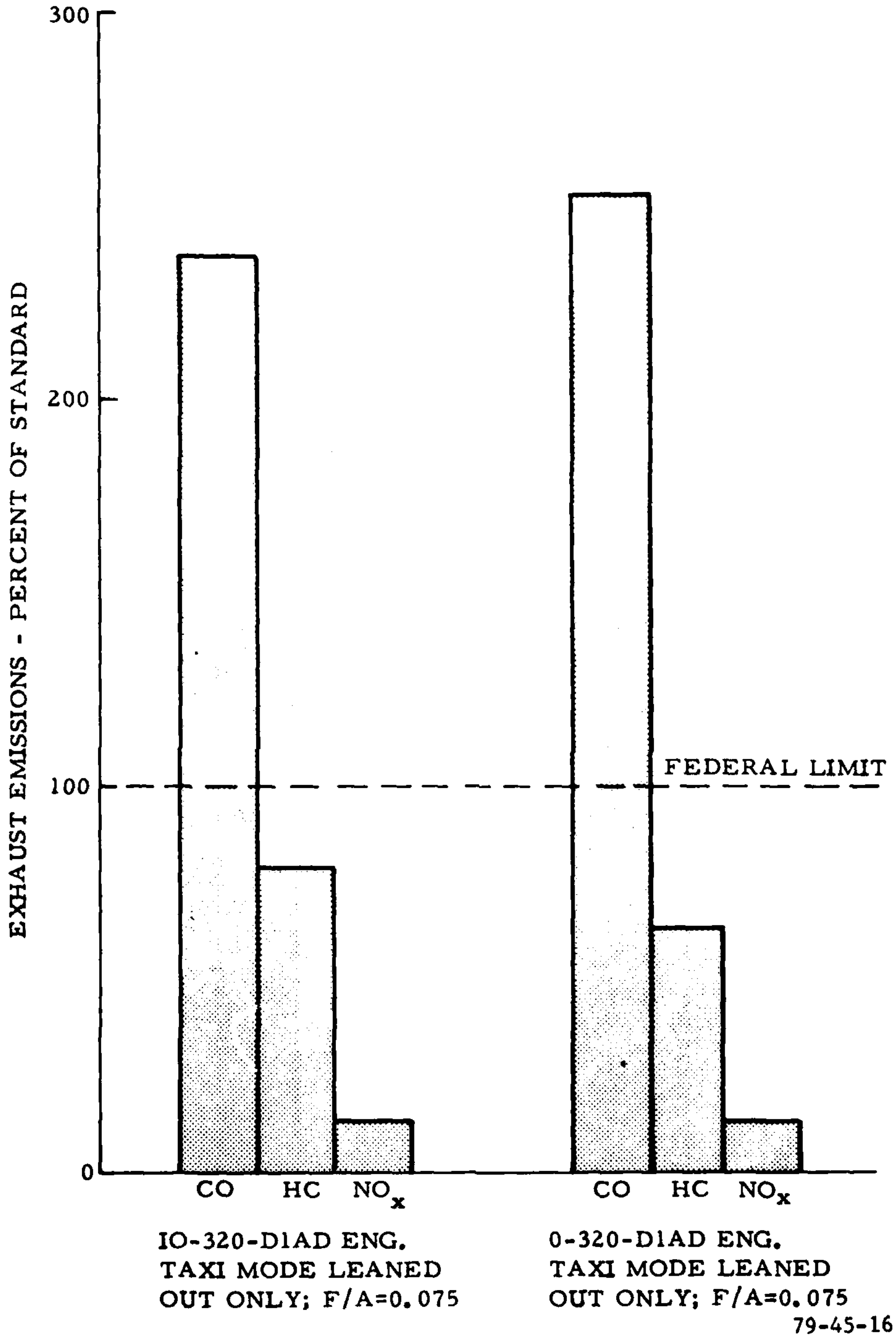


FIGURE 16. TOTAL EMISSIONS CHARACTERISTICS--AVCO LYCOMING IO-320/0-320-DIAD ENGINES OPERATING UNDER NOMINAL SEA LEVEL STANDARD DAY CONDITIONS; TAKEOFF, CLIMB, AND APPROACH MODE F/A's SAME AS FIGURE 15--TABLE 4 EPA LTO CYCLE

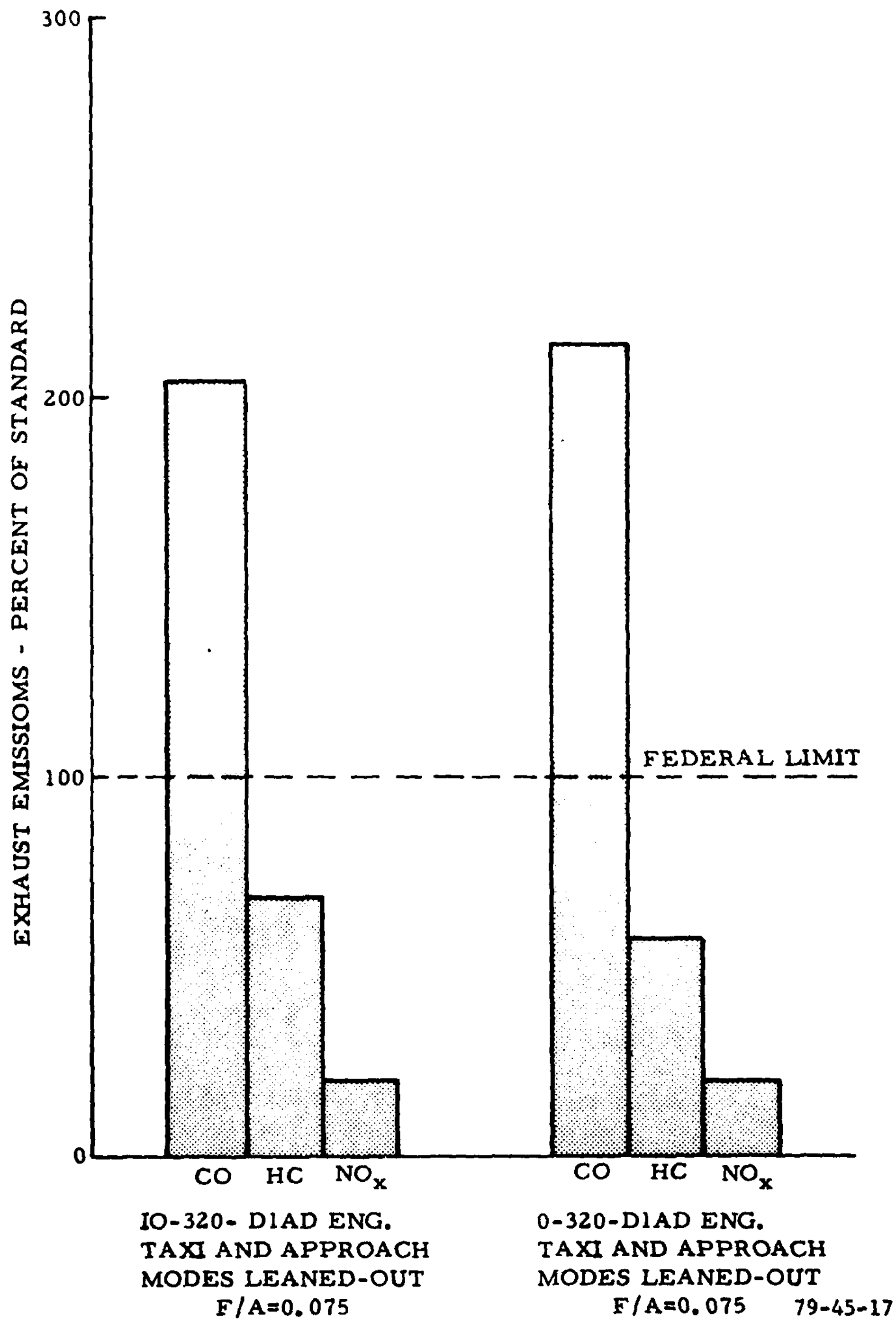


FIGURE 17. TOTAL EMISSIONS CHARACTERISTICS--AVCO LYCOMING IO-320/0-320-DIAD ENGINES OPERATING UNDER NOMINAL SEA LEVEL STANDARD DAY CONDITIONS; TAKEOFF, CLIMB MODE F/A's SAME AS FIGURE 15--TABLE 4 EPA LTO CYCLE

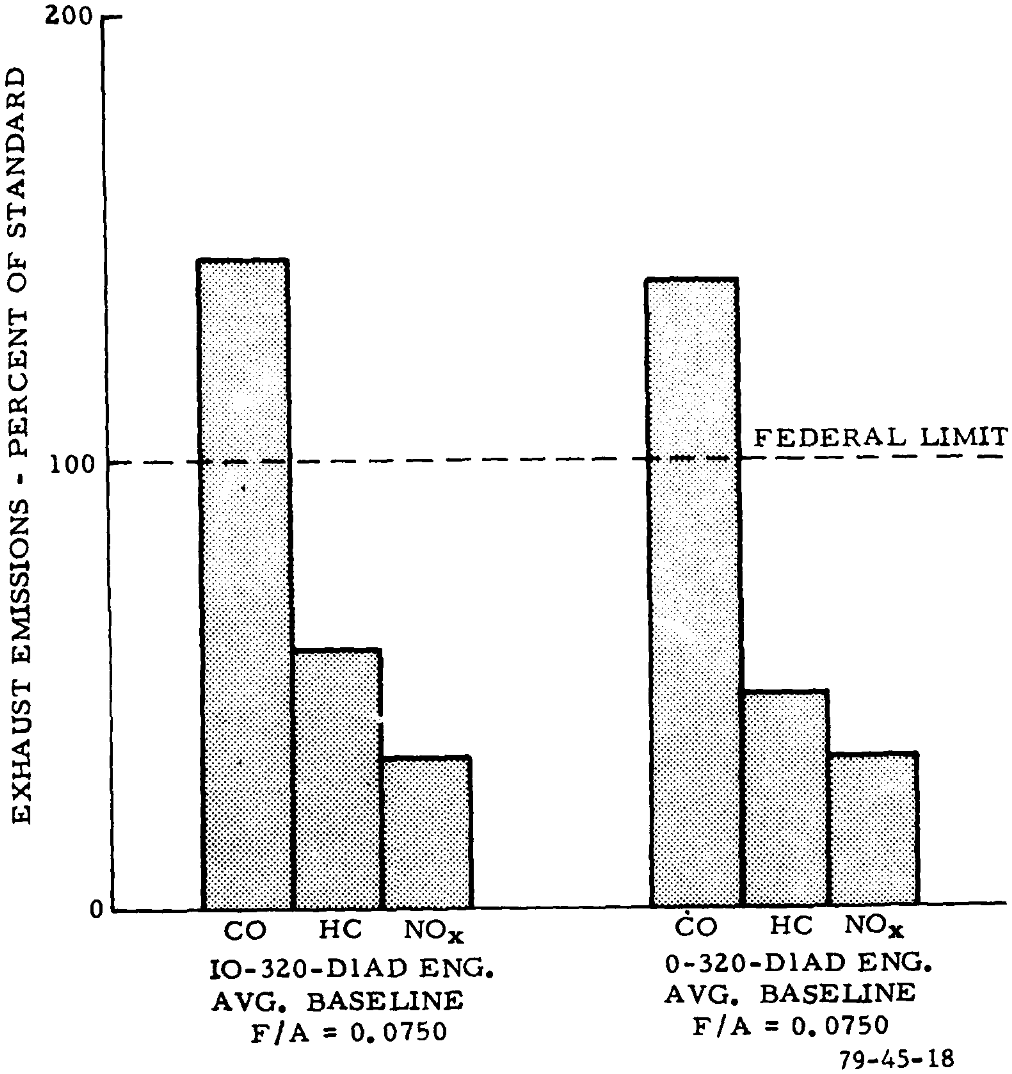


FIGURE 18. TOTAL EMISSIONS CHARACTERISTICS--AVCO LYCOMING IO-320/0-320-DIAD ENGINES OPERATING UNDER NOMINAL SEA LEVEL STANDARD DAY CONDITIONS AND THE SAME AVERAGE, REFERENCE FUEL-AIR RATIO FOR THE TABLE 4 EPA LTO CYCLE

TABLE 6. SUMMARY OF EXHAUST EMISSIONS (CO) REDUCTION POSSIBILITIES FOR AN AVCO LYCOMING IO-320-DIAD ENGINE—NOMINAL SEA LEVEL STANDARD DAY (EXCEPT AS NOTED)—COOLING AIR ΔP = 3.0 inH_2O

	Modes	F/A	CO lb/Mode	Max. CHT-°F	F/A	CO lb/Mode	Max. CHT-°F	Max. CHT-°F	Max.Limit CHT-°F	Max. Service Life Limit High Perf. Cruise-CHT °F	Max. Service Life Limit Economy Cruise CHT-°F
1.	Taxi	0.0900	2.800		0.0750	1.867					
2.	Takeoff (100%)	0.0900	0.588	430	0.0750	0.365	470	475	500		
3.	Climb (100%)	0.0900	9.792	430	0.0750	6.083	470	475	500		
4.	Approach (40%)	0.0900	3.650	355	0.0750	1.450	365	370	500		400
5.	lb/Cycle		16.830			9.765					
6.	lb/Cycle/Rate BHP		0.105			0.061					
7.	Federal Limit		0.042			0.042					
8.	Diff. = 6 - 7		0.063			0.019					
9.	(8 ÷ 7) x 100		150.0			45.2					
10.	% of STD = 9 + 100		250.0			145.2					
				This Column For S.L. Standard Day			This Column For S.L. Standard Day	This Column For S.L. Hot Day		See Ref. 14	See Ref. 14
11.	Taxi	0.0900	2.800		0.0750	1.867					
12.	Takeoff (100%)	0.0900	0.588	430	0.0750	0.365	470	470	500		
13.	Climb (75%)	0.0900	5.583	410	0.0750	2.500	440	445	500	435	
14.	Approach (40%)	0.0900	3.650	322	0.0750	1.450	365	370	500		400
15.	lb/Cycle		12.621			6.182					
16.	lb/Cycle/Rated BHP		0.079			0.039					
17.	Federal Limit		0.042			0.042					
18.	Diff. = 16 - 17		0.037			-.003					
19.	(18 ÷ 17 x 100		88.1			-7.1					
20.	% of STD = 19 + 100		188.1			92.9					

TABLE 7. SUMMARY OF EXHAUST EMISSIONS (CO) REDUCTION POSSIBILITIES FOR AN AVCO LYCOMING IO-320-DIAD ENGINE--NOMINAL SEA LEVEL STANDARD DAY (EXCEPT AS NOTED)--COOLING AIR ΔP = 3.0 inH_2O

	Modes	F/A	CO lb/Mode	Max. CHT-°F	F/A	CO lb/Mode	Max. CHT-°F	Max. CHT-°F	Max.Limit CHT-°F	Max. Service Life Limit High Perf. Cruise-CHT °F	Max. Service Life Limit Economy Cruise CHT-°F
1.	Taxi	0.0900	3.067		0.0750	2.133					
2.	Takeoff (100%)	0.0900	0.592	455	0.0750	0.305	495	500	500		
3.	Climb (100%)	0.0900	9.875	455	0.0750	5.083	495	500	500		
4.	Approach (40%)	0.0900	4.350	335	0.0750	1.850	355	380	500		400
5.	lb/Cycle		17.884			9.371					
6.	lb/Cycle/Rate BHP		0.112			0.059					
7.	Federal Limit		0.042			0.042					
8.	Diff. = 6 - 7		0.070			0.017					
9.	(8 ÷ 7) x 100		166.7			40.5					
10.	% of STD = 9 + 100		266.7			140.5					
				This Column For S.L. Standard Day			This Column For S.L. Standard Day	This Column For S.L. Hot Day		See Ref. 14	See Ref. 14
11.	Taxi	0.0900	3.067		0.0750	2.133					
12.	Takeoff (100%)	0.0900	0.592	455	0.0750	0.305	495	500	500		
13.	Climb ( )	0.0900	6.500	425	0.0750	3.125	440	465	500	435	
14.	Approach	0.0900	4.350	335	0.0750	1.850	355	380	500		400
15.	lb/Cycle		14.509			7.413					
16.	lb/Cycle/Rated BHP		0.091			0.046					
17.	Federal Limit		0.042			0.042					
18.	Diff. = 16 - 17		0.049			0.004					
19.	(18 ÷ 17) x 100		116.7			9.5					
20.	% of STD = 19 + 100		216.7			109.5					

1. Ambient conditions (pressure, temperature, and density)—SL. standard day

2. Fuel schedule—production rich setting (use F/A = 0.090 for both engine configurations)

3. Power setting--100%

4. Measured max. CHT—440° F (for IO-320-DIAD engine)—455° F (for 0-320-DIAD engine)

5. Max. CHT limit—500° F

6. Margin—5 minus 4— 70° F (for IO-320 DIAD engine)--45° F (for 0-320-DIAD engine)

If we now adjust this engine fuel schedule setting to best power or max. CHT limit (all other parameters constant based on above conditions), we now find the following changes take place:

1. CO emissions are improved more than 100% (nominal)

2. Measured max. CHT increases 7.5 to 9.5% (from 430° F to 470° F for the IO-320-DIAD engine and from 455° F to 490° F for the 0-320-DIAD engine)

3. Max. CHT limit--500° F

4. Margin—3 minus 2 = 30° F (IO-320-DIAD engine) and 10° F (0-320-DIAD engine)

5. Reduction in margin (max. CHT)—(40+70) x 100 = 57% (IO-320-DIAD engine) —35+45 x 100 = 78% (0-320-DIAD engine)

EFFECTS OF LEANING-OUT ON HC EMISSIONS. The test data show that the Avco Lycoming 0-320/IO-320-DIAD engine(s) meets the federal standard for unburned hydrocarbon emissions when operating at the production rich limit fuel flows (figures 11, 12, 13, and 14). Additional leaning-out in the taxi, approach, and climb modes provides added improvements, but is not required to produce HC emission levels below the federal standard. However, it should be noted that engine warm-up techniques were utilized prior to the conduct of baseline tests. Pre-baseline warm-up runs usually included a 10-minute engine run at some high power condition above 40 percent power.

EFFECTS OF LEANING-OUT ON NO_x EMISSIONS. Oxides of nitrogen emissions are not improved as a result of applying lean-out adjustments to the fuel metering devices. In fact, the NO_x levels are at their lowest when the engine is operating full rich as shown in figure 11.

EFFECTS ON ALLOWABLE MAXIMUM CYLINDER HEAD TEMPERATURE. One of the major problems that occurs as a result of leaning-out general aviation piston engines in order to improve emissions is the increase or rise in maximum cylinder head temperatures.

Most general aviation aircraft are designed to operate with cooling air pressure differentials of 4.0 inH_2O or less. The tests conducted with the Avco Lycoming O-320/IO-320-DIAD engines utilized 3.0 inH_2O as the basic cooling flow condition, except in the taxi mode where the cooling air ΔP was essentially zero.

No tests were conducted using variations in cooling air flow to evaluate these effects on different lean-out schedules.

Data shown in appendices C and D and plotted in figures 19 and 20 show the results of these tests for nominal sea level standard day conditions.

In summary, it can be concluded that any attempts to lean-out current production-type horizontally opposed general aviation piston engines in the takeoff mode to F/A ratios lower than production lean limits or best power will produce CHT's that are higher than the manufacturer's specified limit.

Any attempt to lean-out the climb mode to F/A ratios below best power will result in higher than normal CHT's. This could become particularly acute under hot-day takeoff and climb conditions at sea level or altitude.

SUMMARY OF RESULTS

EXHAUST EMISSIONS.

1. The O-320/IO-320-DIAD engines do not meet the proposed EPA carbon monoxide standards for 1979/80 under sea level standard-day conditions.

2. The O-320/IO-320-DIAD engine meets the proposed EPA unburned hydrocarbon and oxides of nitrogen standards for 1979/80 under sea level standard-day conditions.

3. The engine fuel metering device could be adjusted on the test stand to reduce the current CO exhaust emission level to approximate the proposed EPA standard for 1979/80 based on table 5 requirements.

4. The highest exhaust emission levels for carbon monoxide and unburned hydrocarbons were measured under the most severe LTO cycle requirements (table 4).

MAXIMUM CYLINDER HEAD TEMPERATURES.

1. Adjusting the fuel metering device in the takeoff mode to constant best power operation results in an increase in maximum CHT, which will exceed the engine specification limit if cooling air ΔP is 3.0 inH_2O or less. This setting will also result in a takeoff condition that has zero tolerance/margin.

2. Adjusting the fuel metering device in the climb mode to constant best power will result in an increase in maximum CHT. This change would necessitate an increase in cooling air flow to provide adequate temperature margins for hot-day operations. An estimated increase in cooling air differential pressure of approximately 1.0 inH_2O may be required for critical aircraft installations.

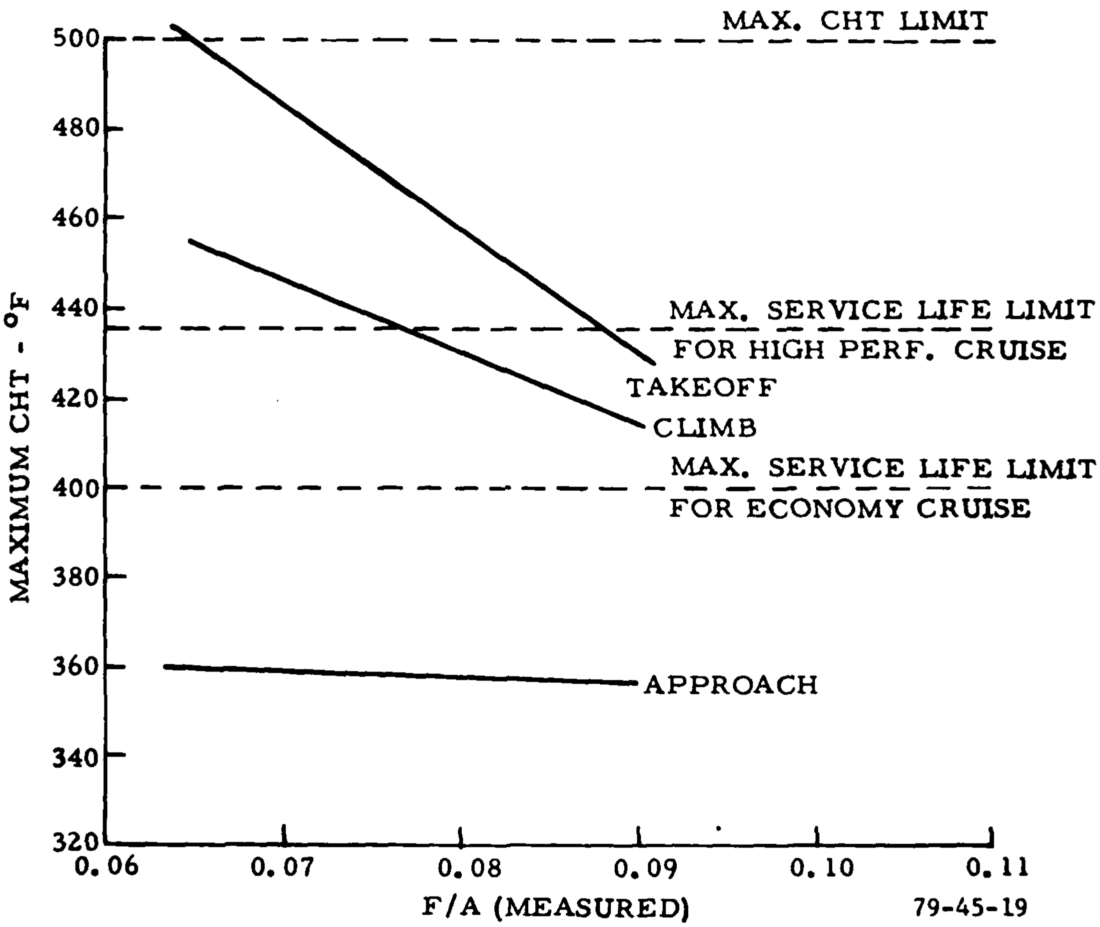


FIGURE 19. SEA LEVEL STANDARD DAY MAXIMUM CYLINDER HEAD TEMPERATURES FOR DIFFERENT POWER MODE CONDITIONS AND VARYING FUEL-AIR RATIOS--AVCO LYCOMING IO-320-DIAD

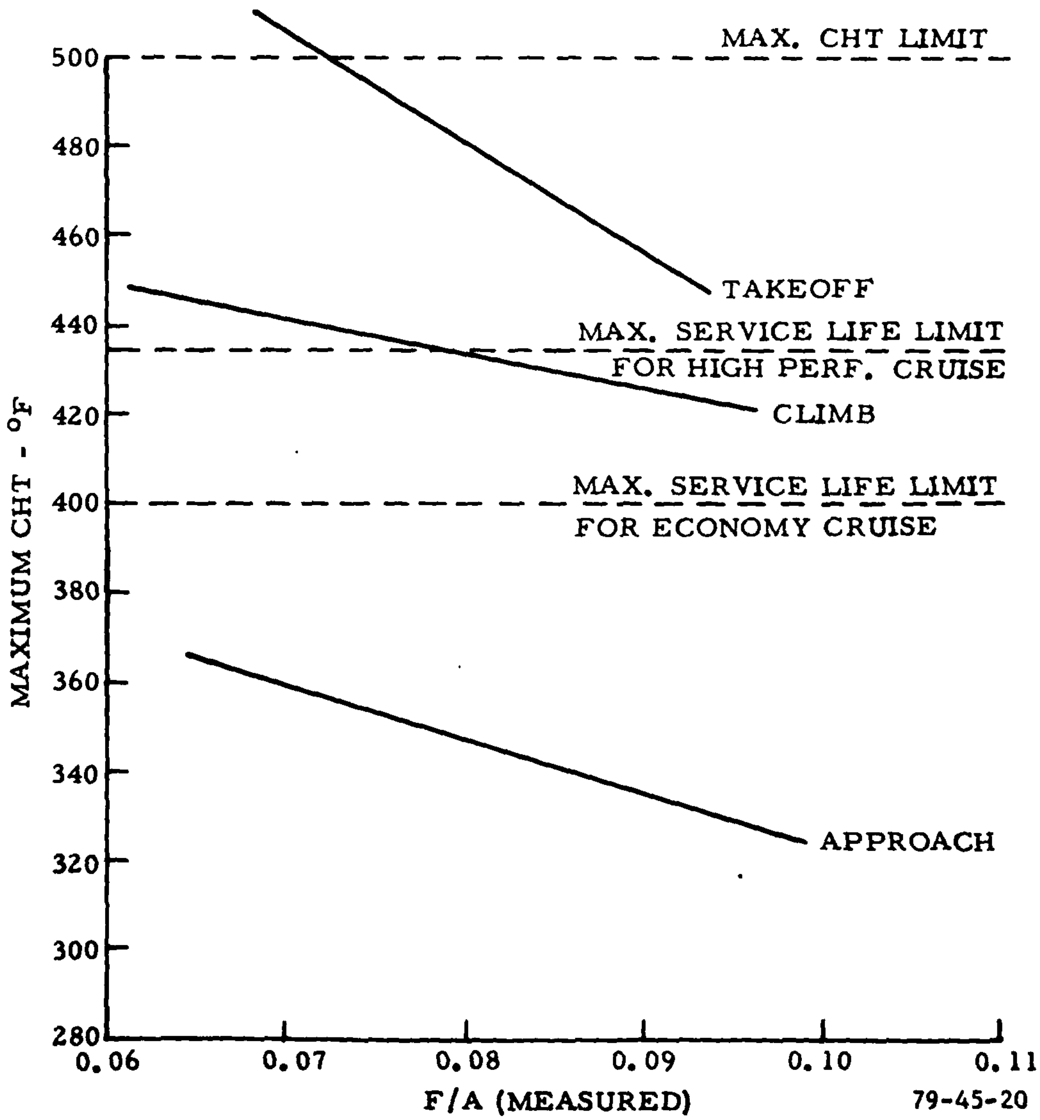


FIGURE 20. SEA LEVEL STANDARD DAY MAXIMUM CYLINDER HEAD TEMPERATURES FOR DIFFERENT POWER MODE CONDITIONS AND VARYING FUEL-AIR RATIOS--AVCO LYCOMING 0-320-DIAD

3. No critical maximum CHT's resulted from leaning-out the approach and taxi modes. However, taxi mode maximum CHT's were measured in excess of 400° F while operating under leaned-out test conditions with no measurable cooling air ΔP, a condition related to actual operation.

4. Based on figures 19 and 20 and reference 14, test results indicate that the manufacture's maximum service life temperature limit can be exceeded for high performance cruise when lean-out operation occur at best power F/A's or lower on a continuous basis.

CRITICAL LANDING AND TAKEOFF CYCLE.

1. The most critical LTO cycle is the cycle defined in this report as the maximum five-mode LTO cycle (table 4). Engine operation in accordance with the maximum five-mode LTO cycle in a sea level propeller test stand could not be adjusted to approximate the proposed EPA CO emission standard for 1979/80 without exceeding maximum CHT limits.

2. Engine operation in accordance with the minimum five-mode LTO cycle (table 5) could be adjusted to meet the proposed EPA emissions standards for 1979/80 without exceeding engine maximum CHT limits while operating with a cooling air $\Delta P = 3.0$ inH_2O in the takeoff, climb, and approach modes and a $\Delta P = 0$ in the taxi mode.

CONCLUSIONS

The following conclusions are based on the testing accomplished with the Avco Lycoming O-320/IO-320-DIAD engine.

1. The single use of simple fuel management adjustments (altering of fuel schedule) do not allow safe reduction of exhaust emissions of the test engine, the Avco Lycoming. In conjuction with other data, references 11, 12, and 13, this appears to be a valid general conclusion for typical light-aircraft piston engines.

2. The test data indicate that fuel management adjustments should be combined with engine/nacelle cooling modifications before a safe, low-emissions aircraft/engine combination can be achieved.

3. The EPA CO limit of 0.042 lb/cycle/rated BHP is too low. This limit appears to be only approximately achievable when hot-day takeoff and climb requirements are impacted by aircraft heavy gross weight and the need to pay close attention to CHT limitations.

4. An assessment of the maximum five-mode LTO cycle (table 4) test data indicate that the following standard changes should be made:

EPA STD For 1979/80 lb/Cycle/Rated BHP	Recommended STD For 1979/80 (lb/Cycle/Rated BHP
CO Standard 0.042	0.075
HC Standard 0.0019	0.0025
NO_x Standard 0.0015	0.0015

5. To avoid CHT problems in the takeoff mode (100 percent power), it is advisable not to adjust the fuel metering device. Engine operation in this mode should continue to be accomplished within current production rich/lean limits. No change in current maximum CHT limitations will then be required.

REFERENCES

1. Control of Air Pollution from Aircraft Engines, Environmental Protection Agency, Federal Register, Volume 38, No. 136, Part II, July 17, 1973.

2. Flow of Fluids Through Valves, Fittings, and Pipe, Crane Industrial Products Group, Technical Paper No. 410, 1957.

3. Liston, J., Power Plants for Aircraft, McGraw-Hill Book Company, Inc., New York, 1953.

4. Obert, E. F., Internal Combustion Engines and Air Pollution, Intext Educational Publishers, New York, 1973.

5. D'Alleva, B. A., Procedure and Charts for Estimating Exhaust Gas Quantities and Compositions, General Motors Corp., Research Laboratories, GMR-372, May 15, 1960.

6. Graf, Gleeson, and Paul, Interpretation of Exhaust Gas Analyses, Engineering Experiment Station, Oregon State Agricultural College, Bulletin Series No. 4, 1934.

7. Guide to Aviation Products, Humble Oil and Refining Company, 1969.

8. NAPTC Fuel Sample Analysis — 100/130 Octane Aviation Gasoline, 1976.

9. G.E. Aircraft Propulsion Data Book, General Electric, 1957.

10. Aeronautical Vest-Pocket Handbook, Pratt and Whitney Aircraft, 1957.

11. Becker, E. E., Exhaust Emissions Characteristics for a General Aviation Light-Aircraft Avco Lycoming IO-360-BIBD Piston Engine, DOT/FAA/NAFEC, Report No. FAA-RD-78-129, 1978.

12. Becker, E. E., Exhaust Emissions Characteristics for a General Aviation Light-Aircraft Avco Lycoming IO-360 A1B6D Piston Engine, DOT/FAA/NAFEC, Report No. FAA-RD-78-142, 1978.

13. Becker, E. E., Exhaust Emission Characteristics for a General Aviation Light-Aircraft Avco Lycoming TIO-540-J2BD Piston Engine, DOT/FAA/NAFEC, Report No. FAA-NA-79-36, 1979.

14. Avco Lycoming Division, Fuel Mixture Leaning Procedures, Service Instruction No. 1094C, January 31, 1969.

APPENDIX A

FUEL SAMPLE ANALYSIS

APPENDIX A

FUEL SAMPLE ANALYSIS

COMBUSTIBLE ELEMENTS IN FUELS (AVIATION FUEL).

1. Carbon and hydrogen are the predominant combustible elements in fuels (aviation type), with small amounts of sulphur as the only other fuel element.

2. Liquid fuels are mixtures of complex hydrocarbons.

3. For combustion calculations, gasoline or fuel oil can be assumed to have the average molecular formula C_8H_{17}.

Note: The Exxon® data presented in table A-1 may be found in reference 7.

TABLE A-1. TYPICAL SPECIFICATIONS FOR AVIATION FUELS

Item	D910-76 Grade 100/130	Exxon Aviation Gas 100/130	D910-70 Grade 115/145	Exxon Aviation Gas 115/145
Freezing Point, °F	-72 Max.	Below -76	-76 Max.	Below -76
Reid Vapor Press., PSI	7.0 Max.	6.8	7.0 Max.	6.8
Sulfur, % by Weight	0.05 Max.	0.02	0.05 Max.	0.02
Lower Heating Value, BTU/lb	18,720 Min.		18,800 Min.	
Heat of Comb. (NET). BTU/lb		18,960		19,050
Distillation, %Evaporated				
At 167° F (Max.)	10	22	10	21
At 167° F (Min.)	40		40	
At 221° F (Max.)	50	76	50	62
At 275° F (Max.)	90	97	90	96
Distillation End Point	338° F Max.		338° F Max.	
Final Boiling Point °F		319		322
Tel Content, ML/U.S. Gal.	4.0 Max.	3.9	4.6 Max.	4.5
Color	Green	Green	Purple	Purple

4. NAFEC used 100/130 (octane rated) aviation gasoline for the piston engine emission tests. The following analysis of a typical fuel sample (table A-2) made at the U.S. Naval Air Propulsion Test Center (NAPTC), Trenton, N.J. (reference 8).

TABLE A-2. ANALYSIS OF NAFEC FUEL SAMPLE, 100/130 FUEL

Item	NAFEC Sample 100/130	Grade 100/130 (MIL-G-5572E) Spec Limits Min.	Distillation % Evaporation	Max.
Freezing Point, °F	Below -76° F			-76
Reid Vapor Press., PSI	6.12	5.5		7.0
Sulfur % By Weight	0.024			0.05
Lower Heating Value BTU/lb		18,700		
Heat of Comb. (NET) BTU/lb	18,900			
Distillation, % Evaporated				
At 158° F	10			
At 167° F (Min.)		167° F	10	
At 167° F (Max.)			40	167° F
At 210° F	40			
At 220° F	50			
At 221° F		221° F	50	
At 242° F	90			
At 275° F		275° F	90	
Distillation End Point	313° F			338° F
Specific Gravity @60° F	0.7071	Report		Report
API Gravity @60° F	68.6	No Limit		
Tel Content, ML/U.S. Gal.	1.84			4.60

Computation for the fuel hydrogen-carbon ratio is based on the fuel net heating value, h_f, equal to 18,900 BTU/lb and figure A-1.

$C/H = 5.6$
$C = 12.011$
$C_8 = 8 \times 12.011 = 96.088$
$H_y = (96.088) \div 5.6 = 17.159$
$H = 1.008$
$Y = (17.159) \div 1.008 = 17.022$ Use $Y = 17$

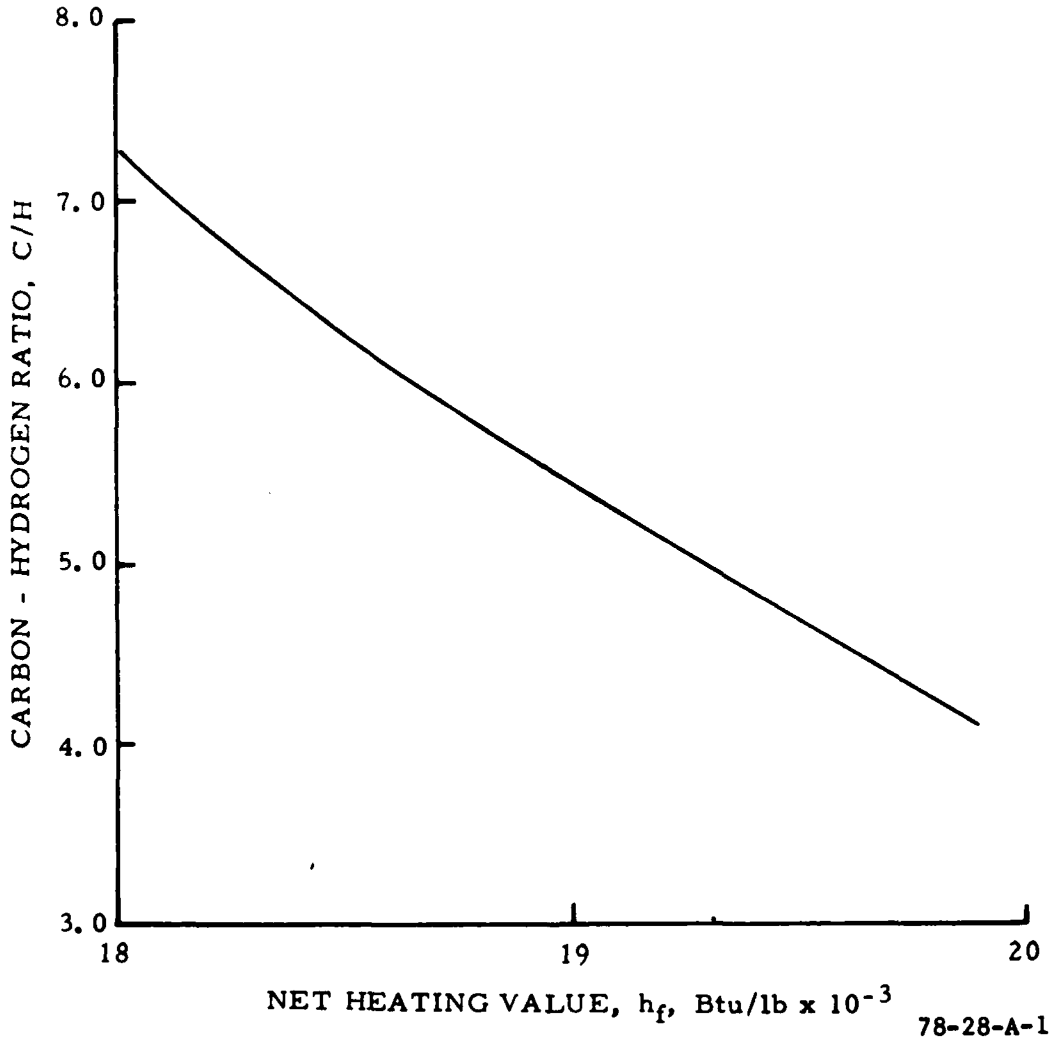


FIGURE A-1. NET HEATING VALUE FOR AVIATION GASOLINE AND CARBON-HYDROGEN RATIO CORRELATION

APPENDIX B

COMPOSITION OF AIR (GENERAL PROPERTIES)

APPENDIX B

COMPOSITION OF AIR (GENERAL PROPERTIES)

1. Dry air is a mixture of gases that has a representative volumetric analysis in percentages as follows:

Oxygen (O_2)—20.99%
Nitrogen (N_2)—78.03%
Argon (A)—0.94% (Also includes traces of the rare gases neon, helium, and krypton)
Carbon Dioxide (CO_2)—0.03%
Hydrogen (H_2)—0.01%

2. For most calculations it is sufficiently accurate to consider dry air as consisting of:

O_2 = 21.0%
N_2 = 79.0% (including all other inert gases)

3. The moisture or humidity in atmospheric air varies over wide limits, depending on meteorological conditions, its presence in most cases simply implies an additional amount of essentially inert material.

Note: Information given in items 1, 2, and 3 is recommended for computation purposes (reference 3, 4, 9, and 10).

TABLE B-1. MASS ANALYSIS OF PURE DRY AIR

Gas	Volumetric Analysis %	Mole Fraction	Molecular Weight	Relative Weight
O_2	20.99	0.2099	32.00	6.717
N_2	78.03	0.7803	28.016	21.861
A	0.94	0.0094	39.944	0.376
CO_2	0.03	0.0003	44.003	0.013
Inert Gases	0.01	0.0001	48.0	0.002
	100.00	1.000		28.969 = M for air

4. The molecular weight of the apparent nitrogen can be similarly determined by dividing the total mass of the inert gases by the total number of moles of these components:

$$M_{\substack{\text{Apparent}\\ \text{Nitrogen}}} = \frac{2225}{79.01} = 28.161$$

5. This appendix advocates the term nitrogen as referring to the entire group of inert gases in the atmosphere and, therefore, the molecular weight of 28.161 will be the correct value (rather than the value 28.016 for pure nitrogen).

6. In combustion processes the active constituent is oxygen (O_2), and the apparent nitrogen can be considered to be inert. Then for every mole of oxygen supplied, 3.764 moles of apparent nitrogen accompany or dilute the oxygen in the reaction:

$$\frac{79.01}{20.99} = 3.764 \frac{\text{Moles Apparent Nitrogen}}{\text{Mole Oxygen}}$$

7. The information given in items 4, 5, and 6 is recommended for computational purposes in reference 4. Therefore, one mole of air (dry), which is composed of one mole of oxygen (O_2) and 3.764 moles of nitrogen (N_2), has a total weight of 137.998 pounds.

$$(O_2 + 3.764\ N_2) = 137.998$$

This gives the molecular weight of air = 28.97.

APPENDIX C

NAFEC TEST DATA AND WORKING PLOTS FOR ANALYSIS AND EVALUATION FOR THE AVCO LYCOMING O-320-DIAD ENGINE

LIST OF ILLUSTRATIONS

Figure		Page
C-1	Measured Performance—Avco Lycoming 0-320-DIAD Engine—Takeoff, Climb, and Approach Modes—Nominal Sea Level Air Density, $\rho_i = 0.0764$ lb/ft^3	C-1
C-2	Measured Performance—Avco Lycoming 0-320-DIAD Engine—Takeoff, Climb, and Approach Modes—Nominal Sea Level Air Density, $\rho_i = 0.0813$ lb/ft^3	C-2
C-3	Airflow as a Function of Induction Air Specific Weight for an Avco Lycoming 0-320-DIAD Engine—Nominal Sea Level Test Data	C-3
C-4	Exhaust Carbon Monoxide as a Function of Induction Air Specific Weight for Several Takeoff Constant Fuel-Flow Schedules—Avco Lycoming 0-320-DIAD Engine	C-4
C-5	Exhaust Carbon Monoxide as a Function of Induction Air Specific Weight for Several Climb Mode Constant Fuel-Flow Schedules—Avco Lycoming 0-320-DIAD Engine	C-5
C-6	Exhaust Carbon Monoxide as a Function of Induction Air Specfic Weight for Several Approach Mode Constant Fuel-Flow Schedules—Avco Lycoming 0-320-DIAD Engine	C-6
C-7	Unburned Exhaust Hydrocarbons as a Function of Induction Air Specific Weight for Several Takeoff Constant Fuel Flow Schedules—Avco Lycoming 0-320-DIAD Engine	C-7
C-8	Unburned Exhaust Hydrocarbons as a Function of Induction Air Specific Weight for Several Climb Mode Constant Fuel-Flow Schedules—Avco Lycoming 0-320-DIAD Engine	C-8
C-9	Unburned Exhaust Hydrocarbons as a Function of Induction Air Specific Weight for Several Approach Mode Constant Fuel-Flow Schedules—Avco Lycoming 0-320-DIAD Engine	C-9
C-10	Oxides of Nitrogen as a Function of Induction Air Specific Weight for Several Takeoff Constant Fuel-Flow Schedules—Avco Lycoming 0-320-DIAD Engine	C-10
C-11	Oxides of Nitrogen as a Function of Induction Air Specific Weight for Several Climb Mode Constant Fuel-Flow Schedules—Avco Lycoming 0-320-DIAD Engine	C-11

LIST OF ILLUSTRATION (Continued)

Figure		Page
C-12	Oxides of Nitrogen as a Function of Induction Air Specific Weight for Several Approach Mode Constant Fuel-Flow Schedules—Avco Lycoming O-320-DIAD Engine	C-12
C-13	Nominal Sea Level Standard Day Emission Characteristics for an Avco Lycoming O-320-DIAD Engine—Carbon Monoxide	C-13
C-14	Nominal Sea Level Standard Day Emissions Characteristics for an Avco Lycoming O-320-DIAD Engine—Unburned Hydrocarbons	C-14
C-15	Nominal Sea Level Standard Day Emissions Characteristics for an Avco Lycoming O-320-DIAD Engine--Oxides of Nitrogen	C-15

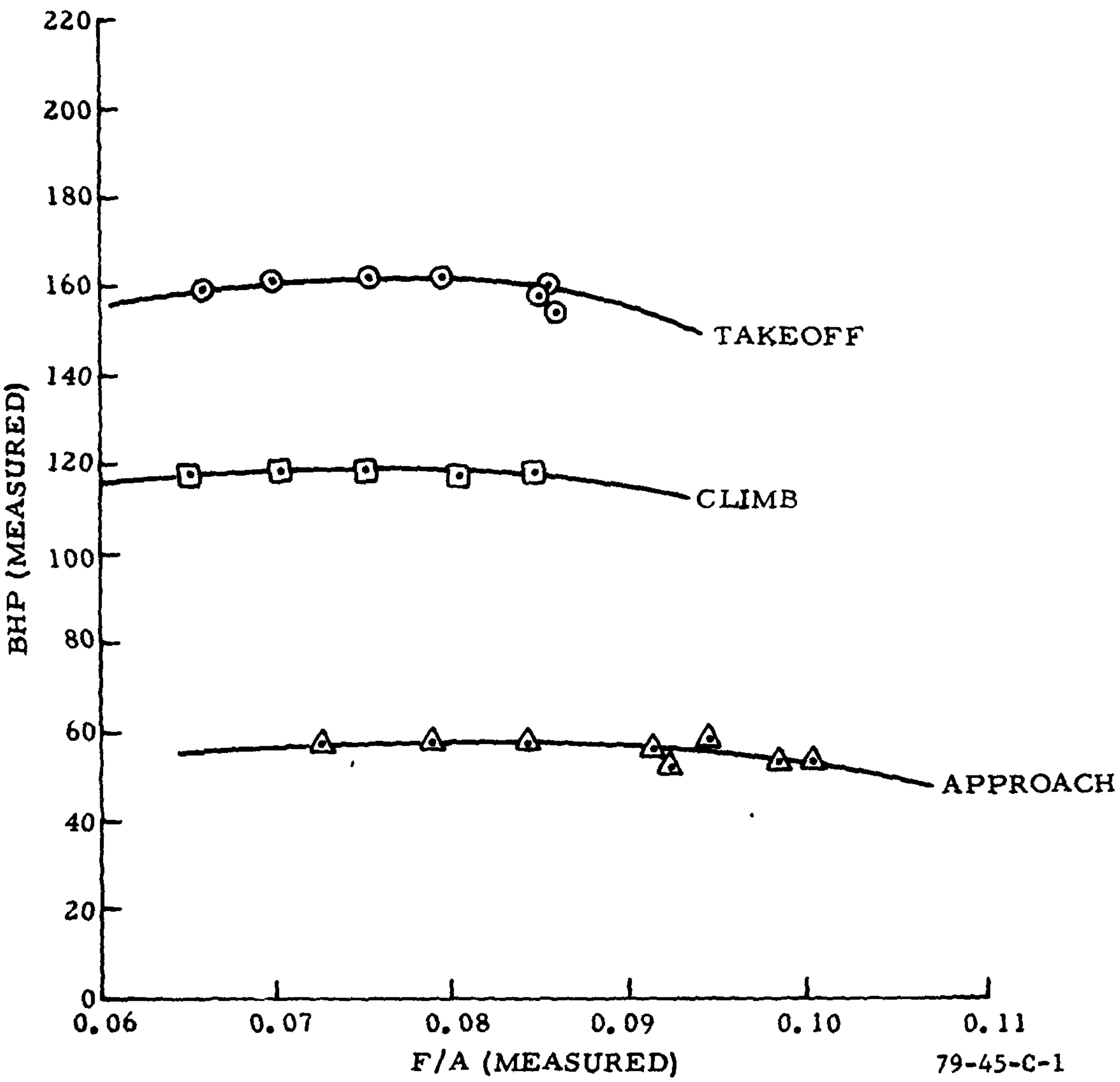


FIGURE C-1. MEASURED PERFORMANCE--AVCO LYCOMING O-320-DIAD ENGINE--TAKEOFF, CLIMB, AND APPROACH MODES--NOMINAL SEA LEVEL INDUCTION AIR DENSITY, $\rho_i = 0.0764$ lb/ft^3

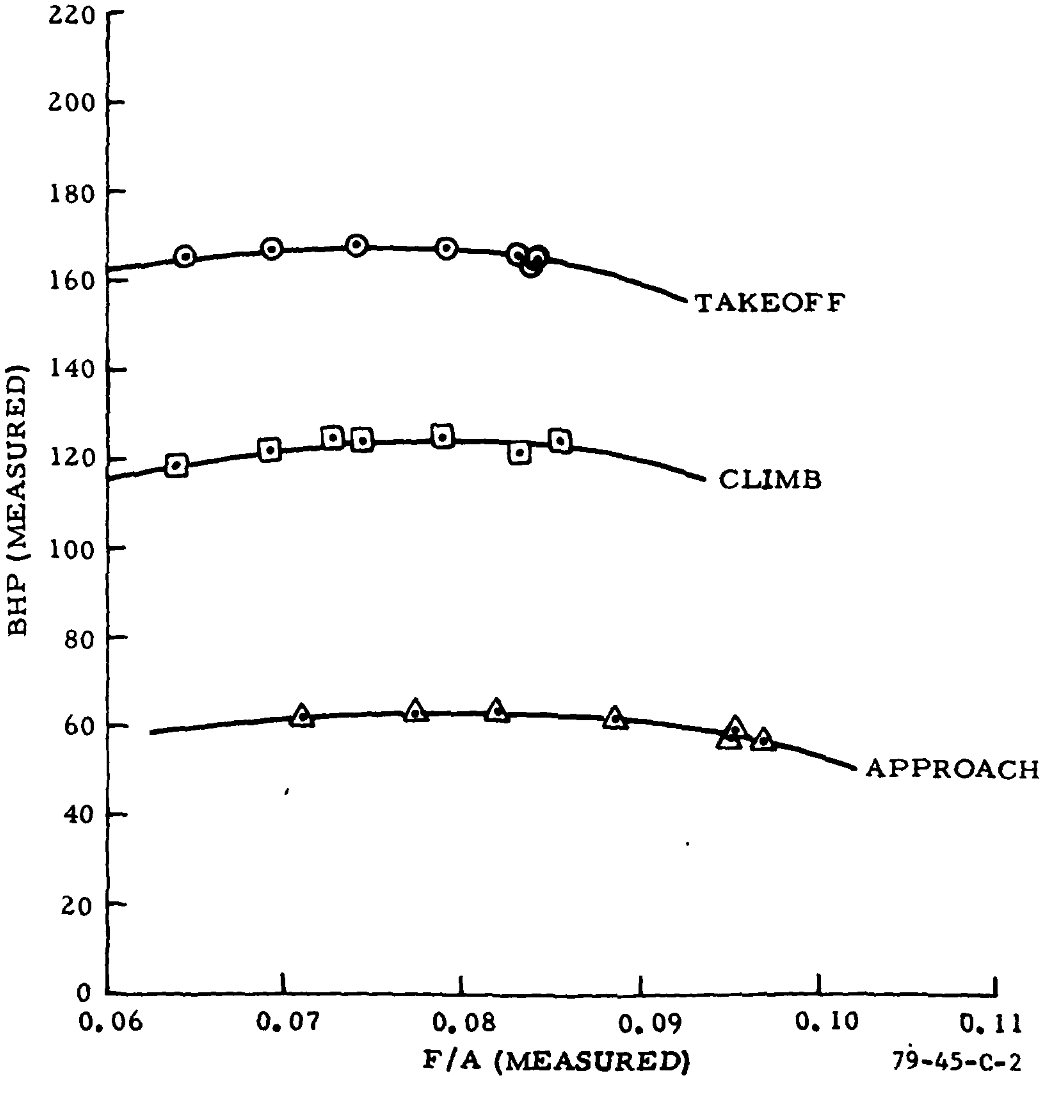


FIGURE C-2. MEASURED PERFORMANCE—AVCO LYCOMING 0-320-DIAD ENGINE—TAKEOFF, CLIMB, AND APPROACH MODES—NOMINAL SEA LEVEL INDUCTION AIR DENSITY, $\rho_1 = 0.0813$ lb/ft^3

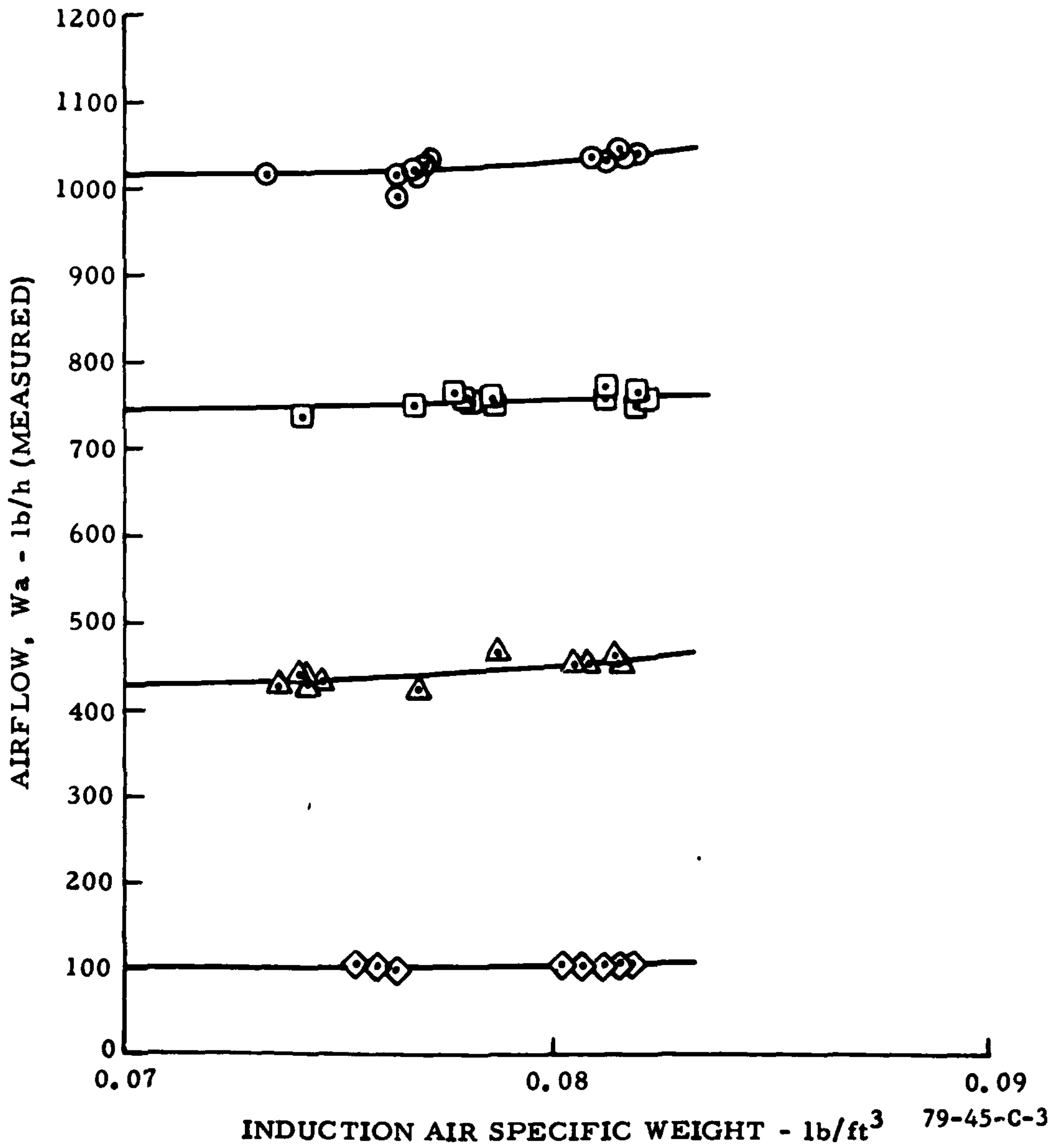


FIGURE C-3. AIRFLOW AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR AN AVCO LYCOMING O-320-DIAD ENGINE--NOMINAL SEA LEVEL TEST DATA

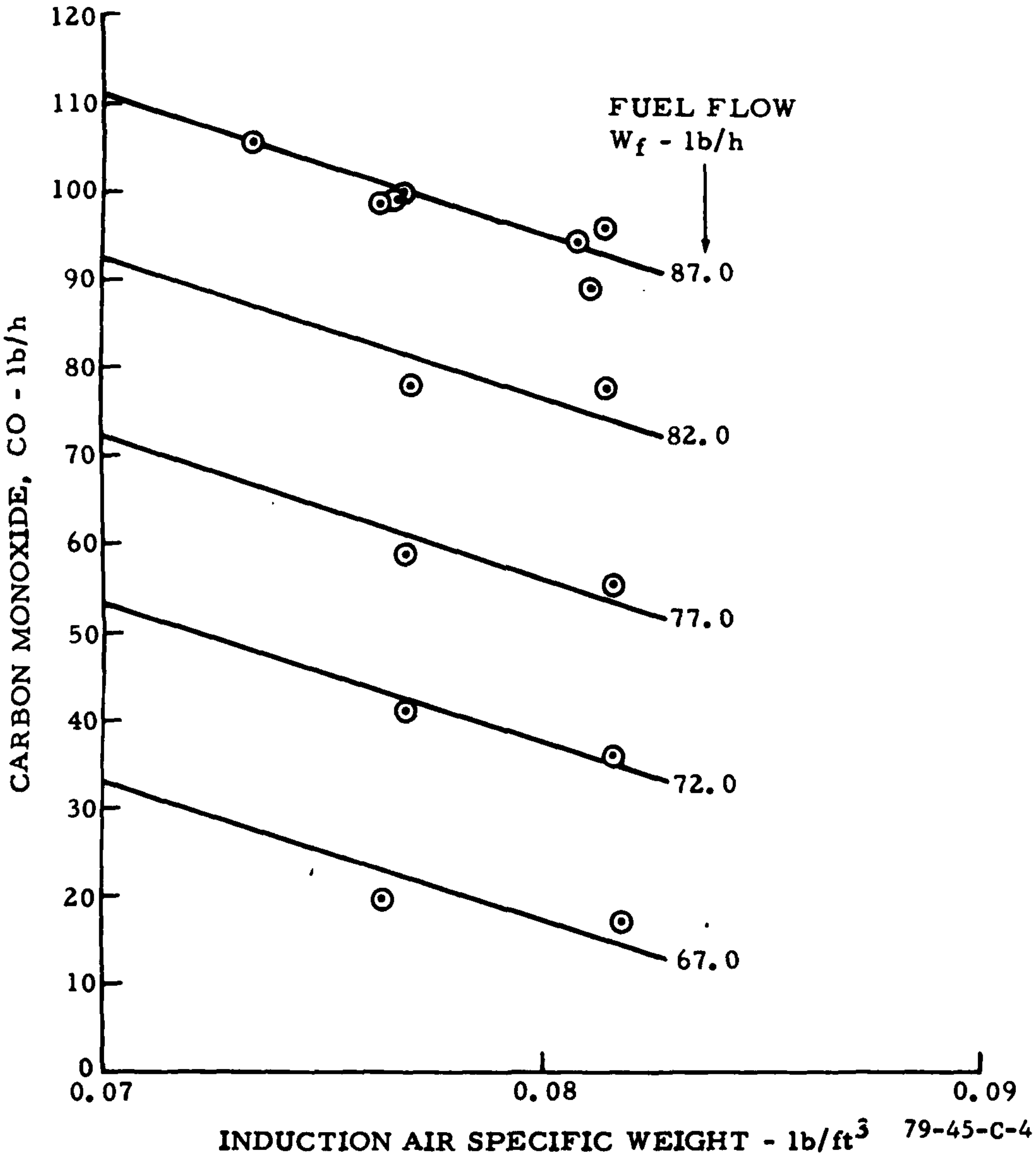


FIGURE C-4. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAKEOFF CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING O-320-DIAD ENGINE

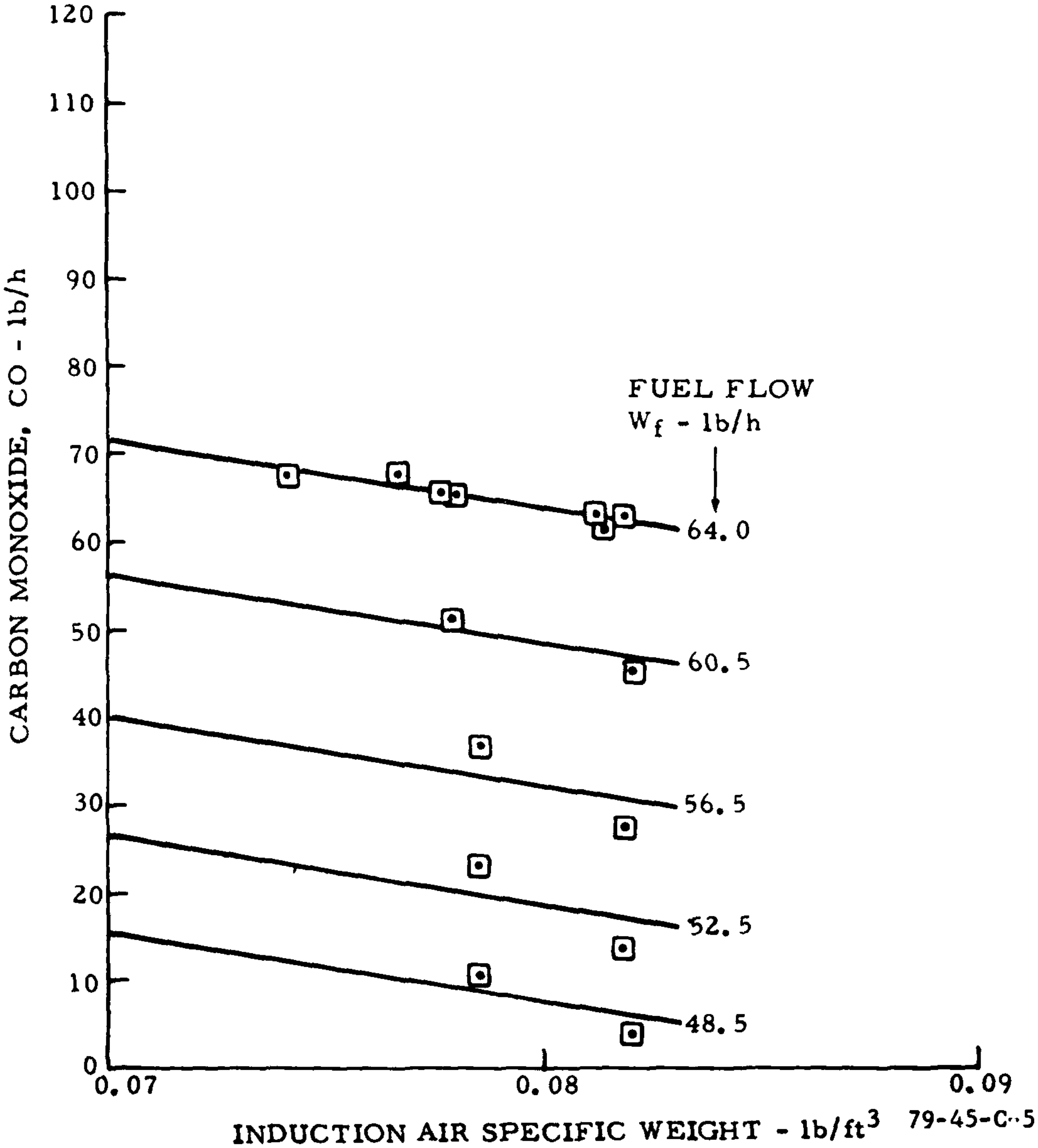


FIGURE C-5. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL CLIMB MODE CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING O-320-DIAD ENGINE

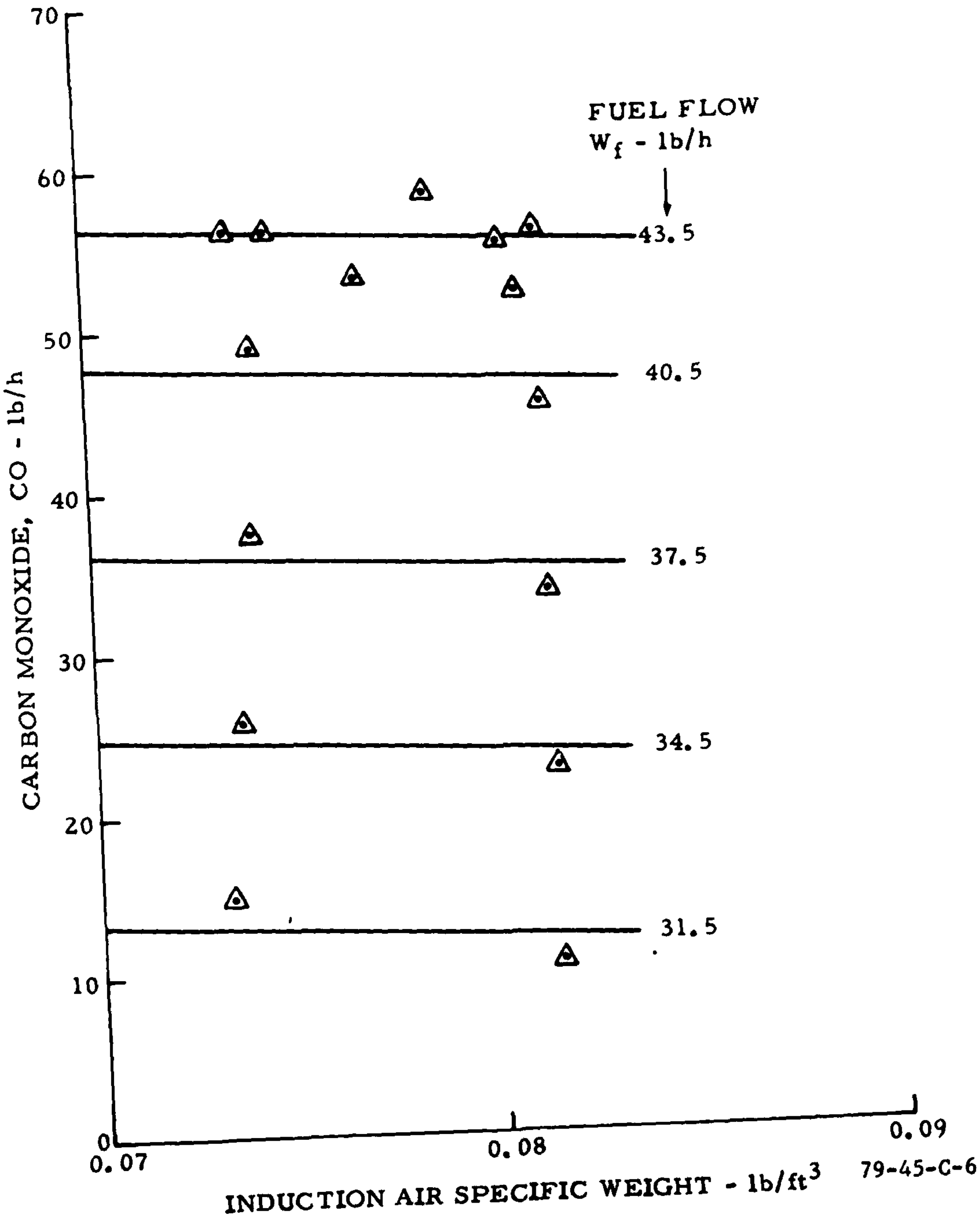


FIGURE C-6. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL APPROACH MODE CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING 0-320-DIAD ENGINE

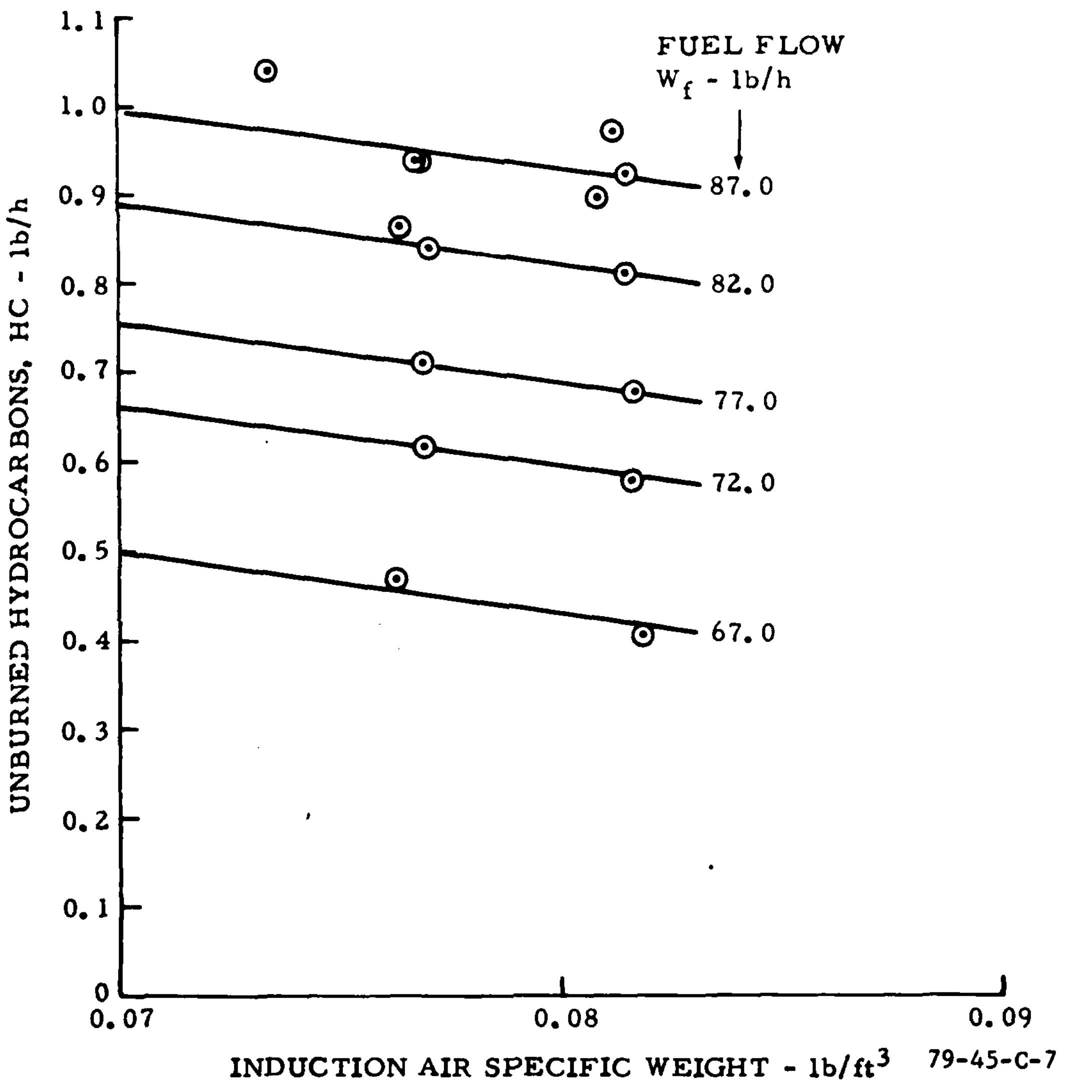


FIGURE C-7. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAKEOFF CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING 0-320-DIAD ENGINE

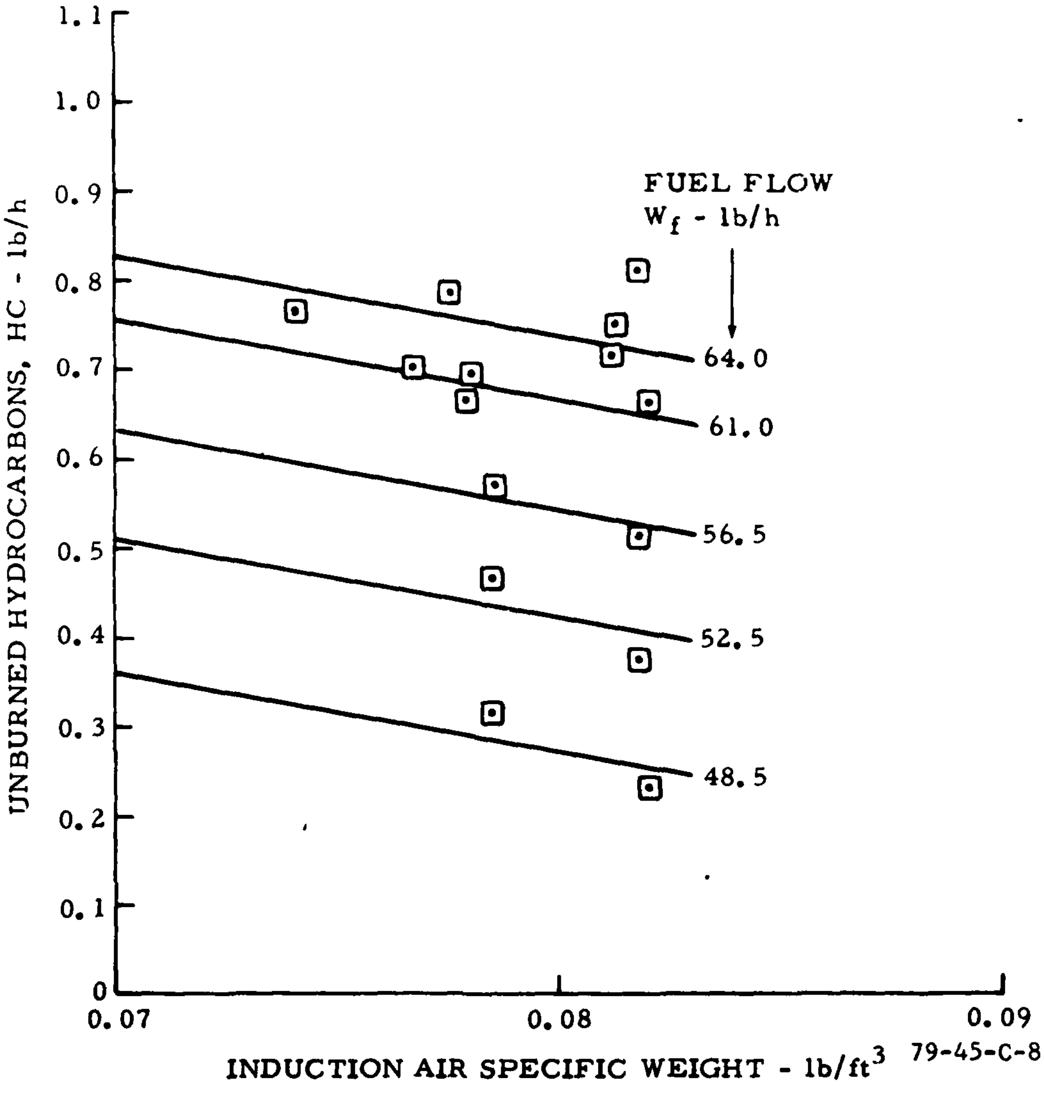


FIGURE C-8. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL CLIMB MODE CONSTANT FUEL-FLOW SCHEDULES—AVCO LYCOMING O-320-DIAD ENGINE

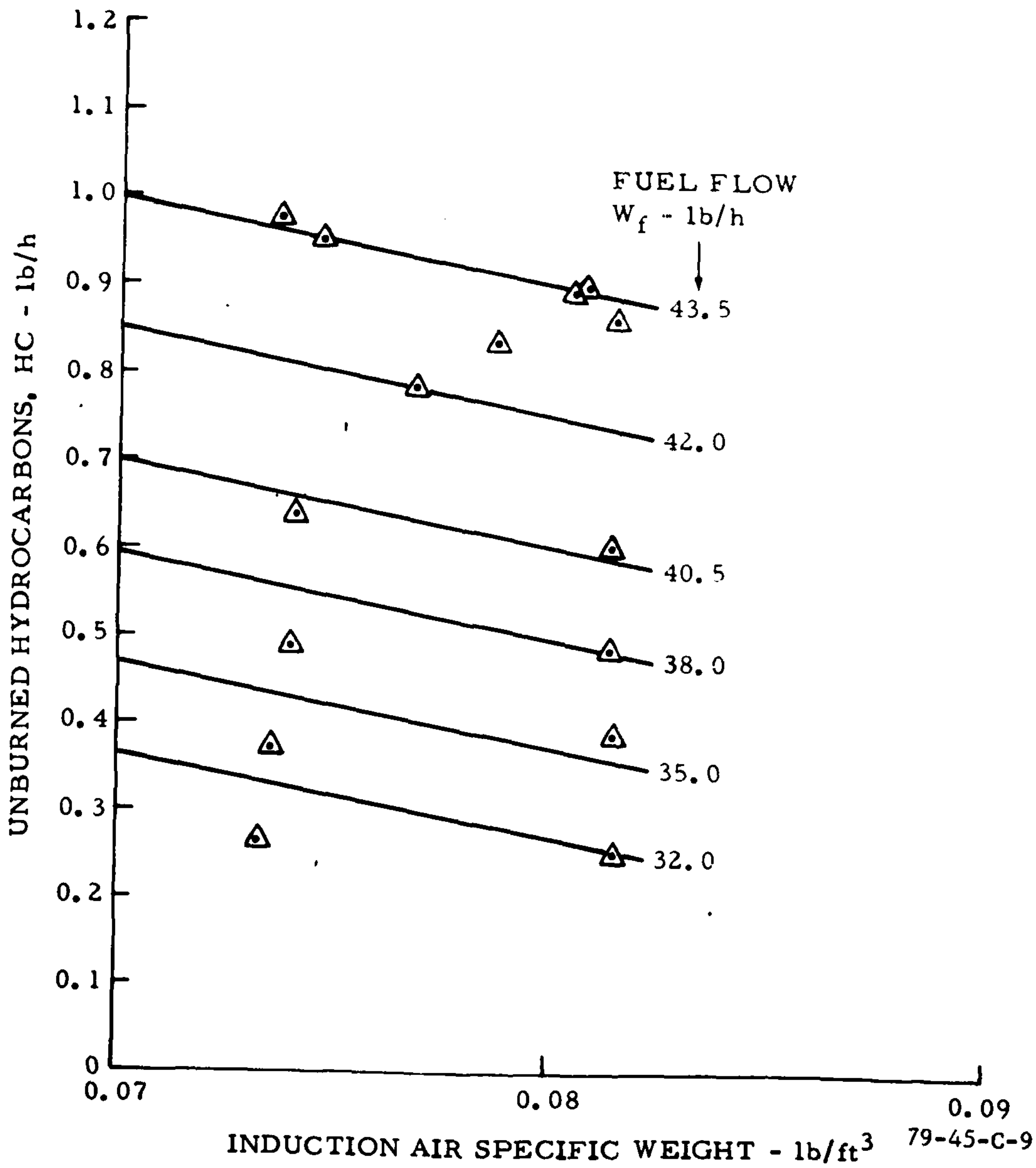


FIGURE C-9. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL APPROACH MODE CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING O-320-DIAD ENGINE

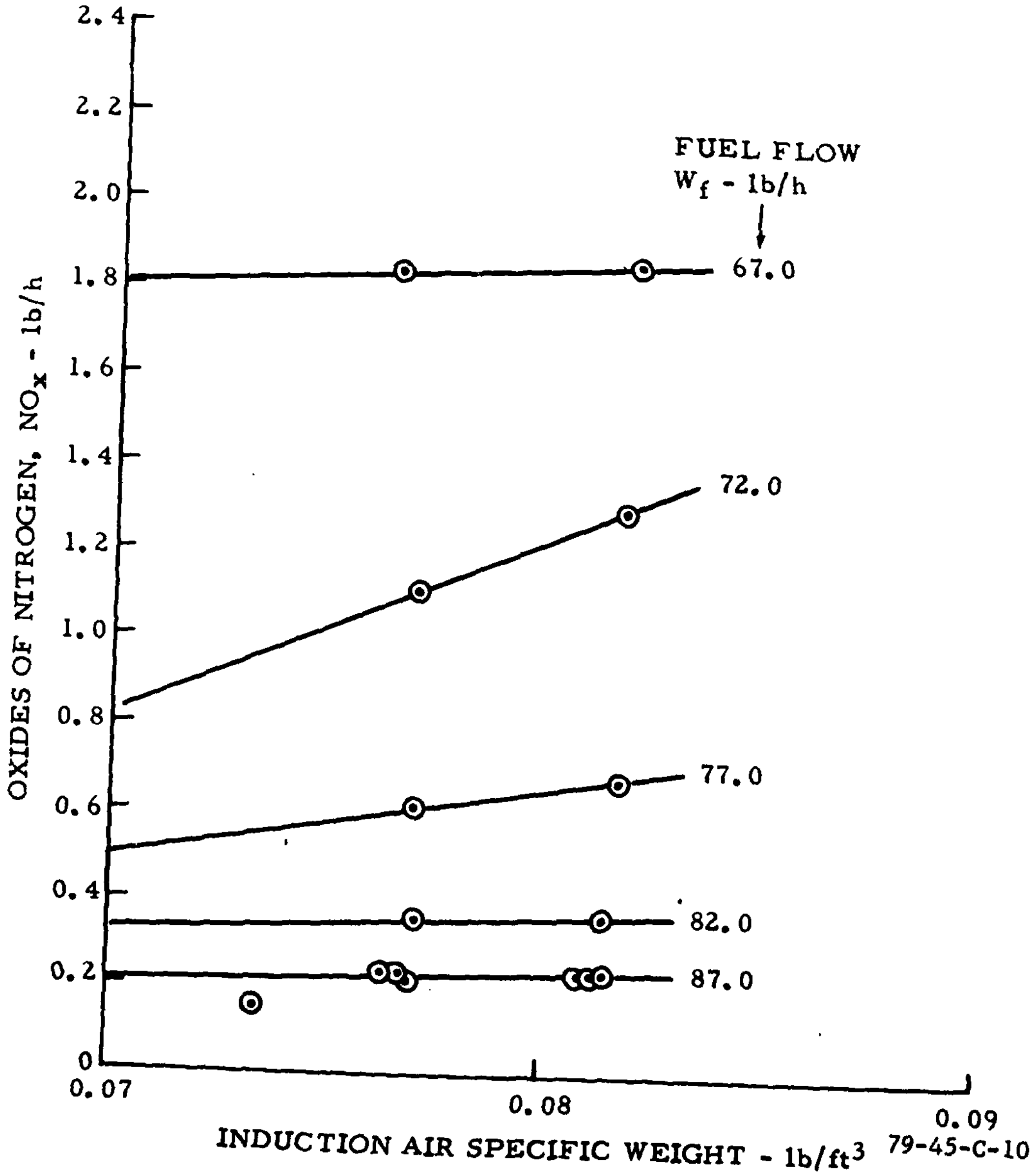


FIGURE C-10. OXIDES OF NITROGEN AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAKEOFF CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING O-320-DIAD ENGINE

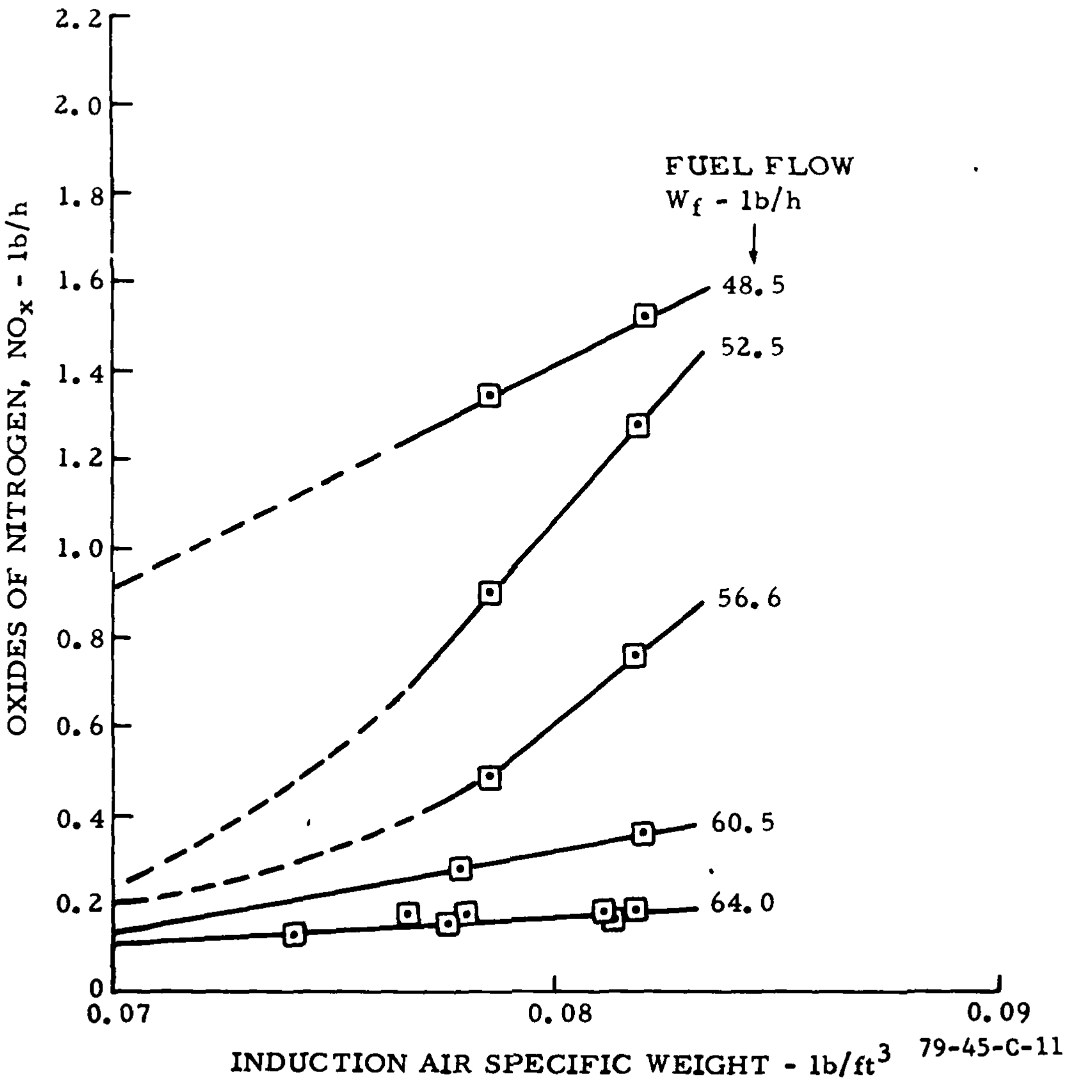


FIGURE C-11. OXIDES OF NITROGEN AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL CLIMB MODE CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING O-320-DIAD ENGINE

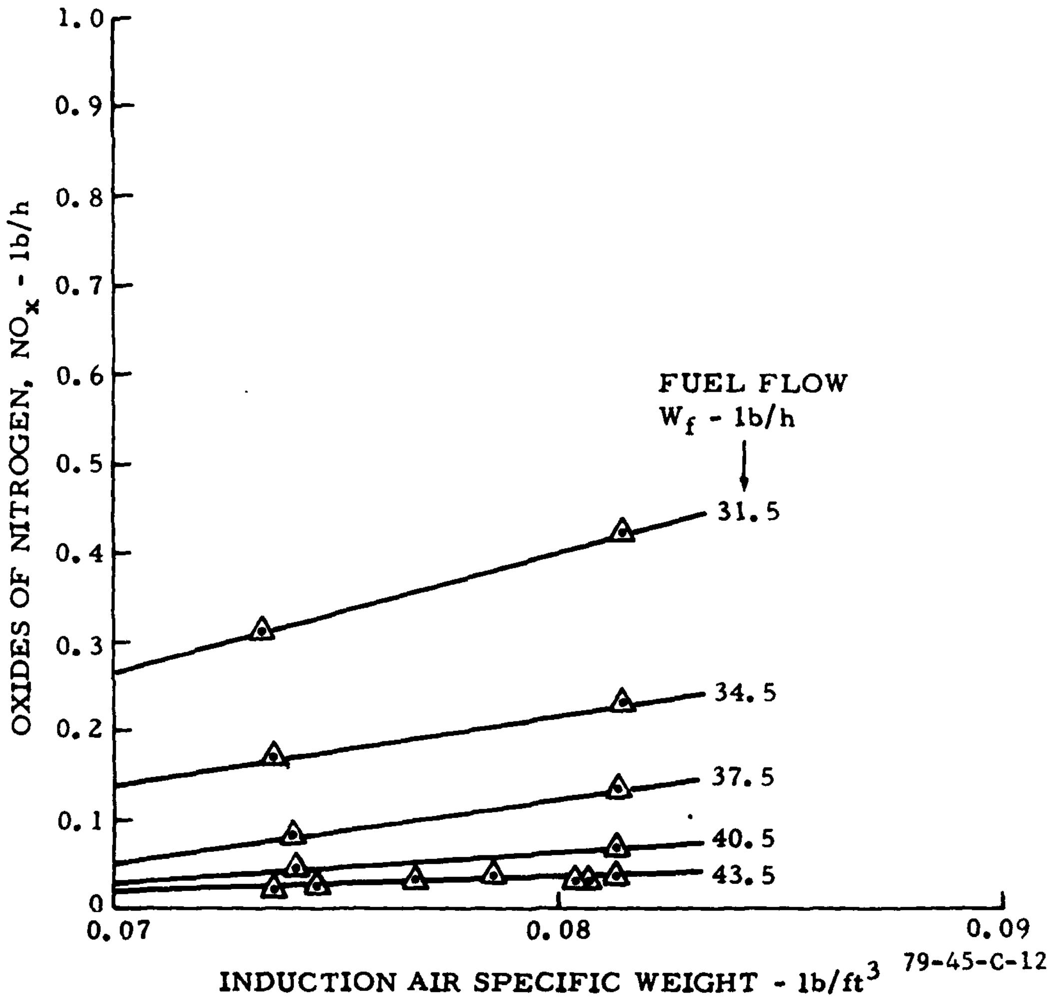


FIGURE C-12. OXIDES OF NITROGEN AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL APPROACH MODE CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING O-320-DIAD ENGINE

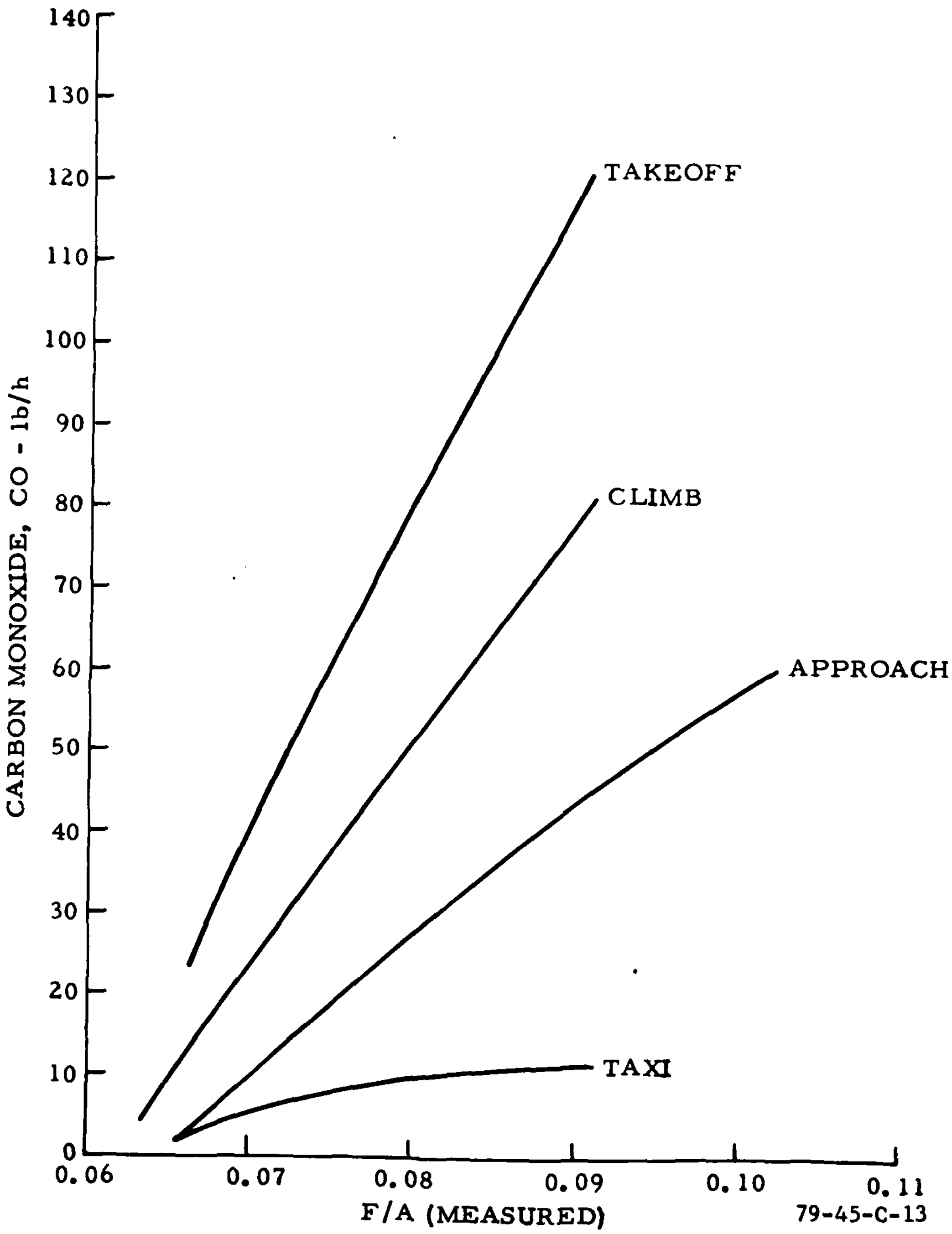


FIGURE C-13. NOMINAL SEA LEVEL STANDARD DAY EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING O-320-DIAD ENGINE--CARBON MONOXIDE

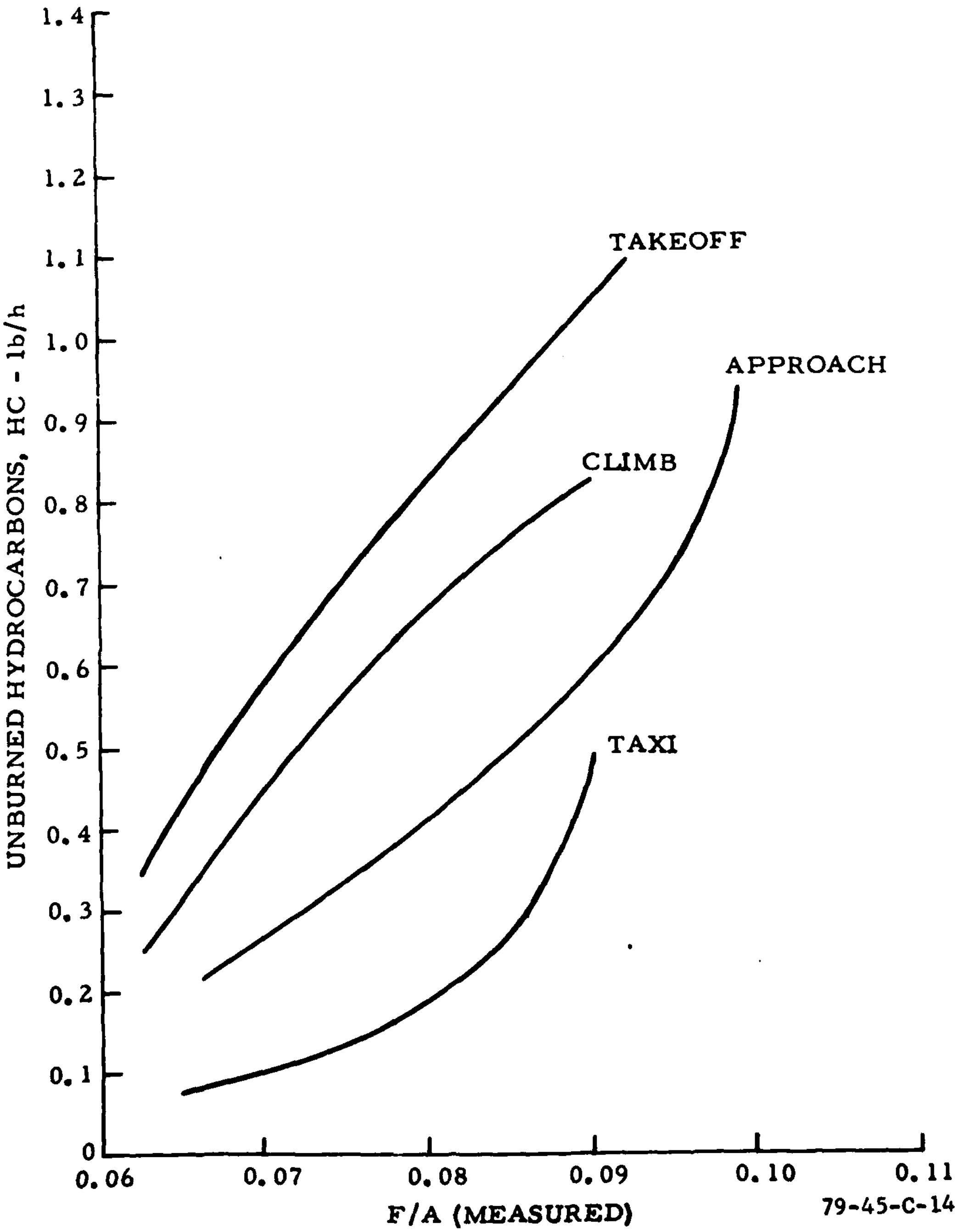


FIGURE C-14. NOMINAL SEA LEVEL STANDARD DAY EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING 0-320-DIAD ENGINE--UNBURNED HYDROCARBONS

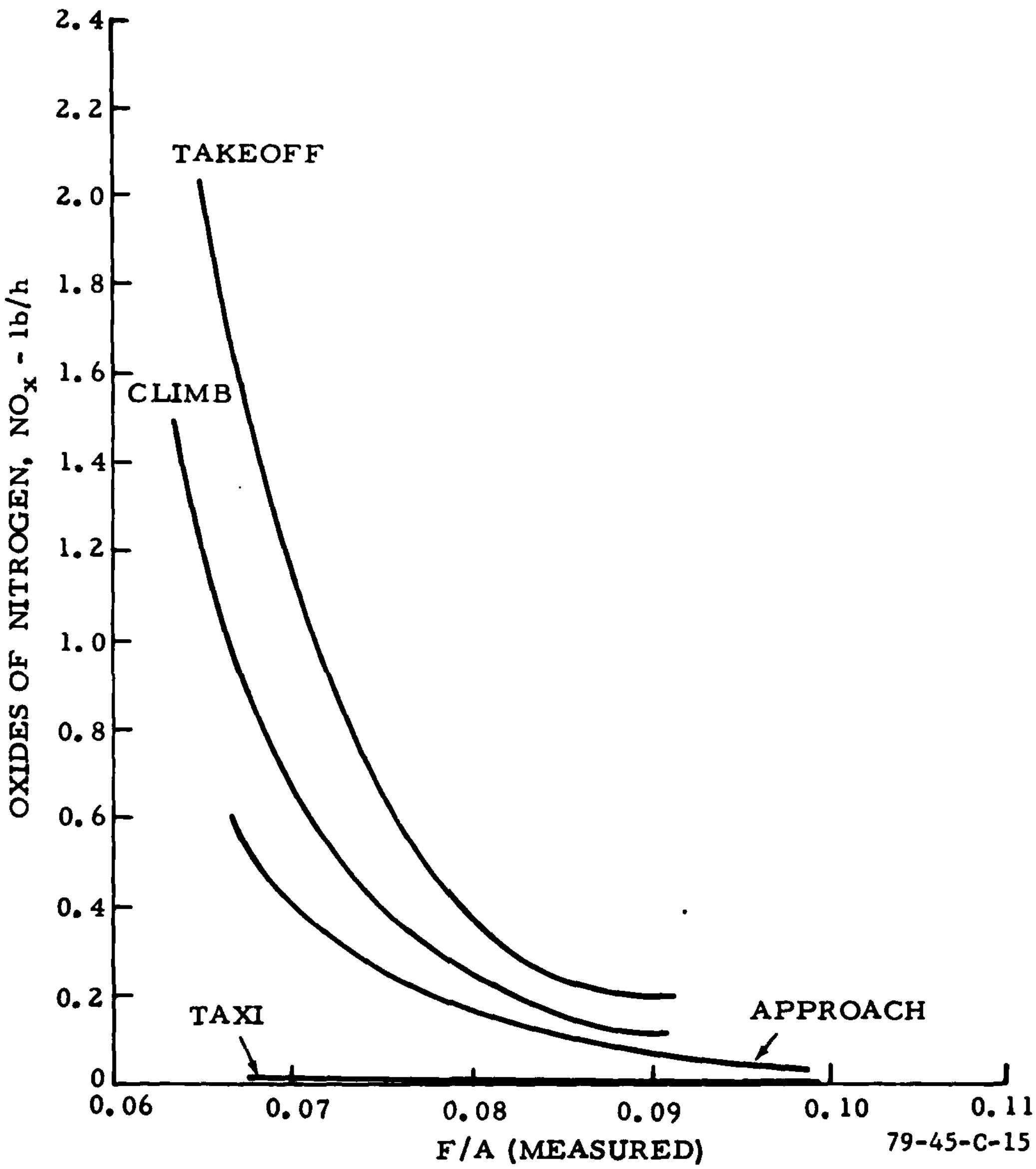


FIGURE C-15. NOMINAL SEA LEVEL STANDARD DAY EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING 0-320-DIAD ENGINE--OXIDES OF NITROGEN

TABLE C-1. AVCO LYCOMING 0-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #1-
(NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

	Run No.	952	953	954	955	956
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		29.24	29.24	29.24	29.24	29.24
2. Spec. Hum. - lb/lb		0.0045	0.0045	0.0045	0.0045	0.0045
3. Induct. Air Temp.-°F		59	54	52	51	51
4. Cooling Air Temp.-°F		-	46	44	44	-
5. Induct. Air Press.-inHgA		29.62	29.59	29.62	29.62	29.62
6. Engine Speed - RPM		1200	2700	2430	2290	1200
7. Manifold Air Press.-inHgA		11.0	28.7	26.0	18.0	11.1
8. Induct. Air Density-lb/ft^3		0.0756	0.0763	0.0767	0.0768	0.0768
9. Fuel Flow, W_f-lb/h		8.3	85.0	61.0	39.0	9.3
10. Airflow, W_a-lb/h		102.4	990.0	749.0	442.0	107.9
11. F/A (Measured) = 9 / 10		0.0811	0.0859	0.0814	0.0924	0.0862
12. Max. Cht - °F		356	446	409	303	353
13. Avg. Cht - °F		347	421	394	296	344
14. Min. Cht - °F		341	393	378	289	338
15. EGT - °F		564	1284	1199	1025	593
16. Torque, lb-ft		28	300	246	118	30
17. Obs. Bhp		6	154	114	51.5	7
18. % CO_2 (Dry)		8.02	8.14	8.50	6.78	7.88
19. % CO (Dry)		10.14	10.07	9.25	12.28	10.34
20. % O_2 (Dry)		0.29	0.20	0.24	0.23	0.26
21. HC-ppm (Wet)		4381	1509	1711	2856	4518
22. NO_x-ppm (Wet)		41	144	165	47	41
23. CO_2-lb/hr		12.8	125.3	97.9	46.1	13.3
24. CO-lb/hr		10.3	98.7	67.8	53.1	11.1
25. O_2-lb/hr		0.34	2.24	2.01	1.14	0.32
26. HC-lb/hr		0.28	0.863	0.701	0.785	0.313
27. NO_x-lb/hr		0.005	0.229	0.117	0.031	0.006
28. CO-lb/Mode		2.058	0.493	5.650	5.315	0.739
29. HC-lb/Mode		0.0566	0.0043	0.0584	0.0785	0.0209
30. NO_x-lb/Mode		0.0010	0.0011	0.0147	0.0031	0.0004

TABLE C-2. AVCO LYCOMING 0-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #2-
(NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

Parameter	Mode / Run No.	1 Taxi Out	2 Takeoff	3 Climb	4 Approach	5 Taxi In
1. Act. Baro. - inHgA		30.12	30.12	30.12	30.12	30.12
2. Spec. Hum. - lb/lb		0.0010	0.0010	0.0010	0.0010	0.0010
3. Induct. Air Temp.-°F		45	40	39	39	39
4. Cooling Air Temp.-°F		-	31	30	30	-
5. Induct. Air Press.-inHgA		30.53	30.50	30.55	30.27	30.53
6. Engine Speed - RPM		1200	2700	2430	2310	1200
7. Manifold Air Press.-inHgA		10.0	28.6	26.0	18.0	10.0
8. Induct. Air Density-lb/ft^3		0.0801	0.0808	0.0811	0.0804	0.0811
9. Fuel Flow, W_f-lb/h		8.1	87.0	63.0	43.0	8.2
10. Airflow, W_a-lb/h		105.2	1034.0	760.0	452.0	105.8
11. F/A (Measured) = 9 / 10		0.0770	0.0841	0.0829	0.0951	0.0775
12. Max. Cht - °F		351	451	418	312	348
13. Avg. Cht - °F		343	422	400	304	335
14. Min. Cht - °F		338	388	381	296	326
15. EGT - °F		552	1298	1222	1032	564
16. Torque, lb-ft		33	321	270	132	34
17. Obs. Bhp		8	165	125	58.0	8
18. % CO_2 (Dry)		8.48	8.74	9.12	7.14	8.49
19. % CO (Dry)		9.66	9.26	8.54	11.91	9.59
20. % O_2 (Dry)		0.25	0.20	0.23	0.23	0.29
21. HC-ppm (Wet)		3264	1359	1484	2834	3514
22. NO_x-ppm (Wet)		49	193	200	59	46
23. CO_2-lb/hr		13.9	139.8	106.1	51.9	14.0
24. CO-lb/hr		10.1	94.3	63.3	55.1	10.0
25. O_2-lb/hr		0.30	2.33	1.95	1.22	0.35
26. HC-lb/hr		0.21	0.897	0.715	0.895	0.21
27. NO_x-lb/hr		0.006	0.231	0.180	0.031	0.004
28. CO-lb/Mode		2.012	0.471	5.271	5.514	0.669
29. HC-lb/Mode		0.0426	0.0045	0.0596	0.0895	0.0143
30. NO_x-lb/Mode		0.0012	0.0012	0.0150	0.0031	0.0003

TABLE C-3. AVCO LYCOMING 0-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #3- (NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

	Run No.	26	27	28	29	30
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		30.16	30.16	30.16	30.16	30.16
2. Spec. Hum. - lb/lb		0.0015	0.0015	0.0015	0.0015	0.0015
3. Induct. Air Temp.-°F		43	39	38	38	38
4. Cooling Air Temp.-°F		-	32	30	30	-
5. Induct. Air Press.-inHgA		30.58	30.54	30.56	30.31	30.58
6. Engine Speed - RPM		1200	2700	2430	2325	1200
7. Manifold Air Press.-inHgA		10.1	28.6	26.0	18.0	10.0
8. Induct. Air Density-lb/ft^3		0.0806	0.0811	0.0813	0.0807	0.0814
9. Fuel Flow, W_f-lb/h		8.4	87.0	66.0	44.0	8.5
10. Airflow, W_a-lb/h		103.8	1036.0	773.0	454.0	105.2
11. F/A (Measured) = 9 / 10		0.0809	0.0840	0.0854	0.0969	0.0808
12. Max. Cht - °F		364	448	415	323	338
13. Avg. Cht - °F		353	423	400	312	323
14. Min. Cht - °F		346	391	383	304	308
15. EGT - °F		564	1270	1200	1006	535
16. Torque, lb-ft		28	319	268	130	30
17. Obs. Bhp		6	164	124	57.5	7
18. % CO_2 (Dry)		8.33	8.49	8.83	6.79	7.20
19. % CO (Dry)		9.75	8.79	8.14	11.23	8.21
20. % O_2 (Dry)		0.29	1.03	0.93	1.27	3.18
21. HC-ppm (Wet)		3363	1475	1525	2988	3260
22. NO_x-ppm (Wet)		44	187	183	55	37
23. CO_2-lb/hr		13.5	135.5	104.2	49.3	11.6
24. CO-lb/hr		10.0	89.3	61.1	51.9	8.5
25. O_2-lb/hr		0.34	12.0	7.98	13.0	3.74
26. HC-lb/hr		0.22	0.97	0.75	0.90	0.22
27. NO_x-lb/hr		0.005	0.231	0.169	0.031	0.004
28. CO-lb/Mode		2.004	0.446	5.095	5.188	0.564
29. HC-lb/Mode		0.0440	0.0049	0.0629	0.0904	0.0144
30. NO_x-lb/Mode		0.0011	0.0012	0.0141	0.0031	0.0003

TABLE C-4. AVCO LYCOMING 0-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #4- (NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

	Parameter	Run No. / Mode	80 Taxi Out	81 Takeoff	82 Climb	83 Approach	84 Taxi In
1.	Act. Baro. - inHgA		30.47	30.47	30.47	30.47	30.47
2.	Spec. Hum. - lb/lb		0.0010	0.0010	0.0010	0.0010	0.0010
3.	Induct. Air Temp.-°F		65	70	66	59	61
4.	Cooling Air Temp.-°F		-	71	63	56	-
5.	Induct. Air Press.-inHgA		30.46	30.69	30.94	30.77	30.43
6.	Engine Speed - RPM		1200	2700	2430	2330	1200
7.	Manifold Air Press.-inHgA		10.0	28.5	26.0	18.0	10.0
8.	Induct. Air Density-lb/ft^3		0.0769	0.0767	0.0780	0.0786	0.0774
9.	Fuel Flow, W_f-lb/h		9.0	87.0	65.0	44.0	8.7
10.	Airflow, W_a-lb/h		106.3	1022.0	753.0	465.0	105.1
11.	F/A (Measured) = 9 / 10		0.0847	0.0851	0.0863	0.0946	0.0828
12.	Max. Cht - °F		344	474	428	324	339
13.	Avg. Cht - °F		331	443	414	315	326
14.	Min. Cht - °F		318	404	398	307	316
15.	EGT - °F		571	1285	1219	1037	565
16.	Torque, lb-ft		28	308	260	130	29
17.	Obs. Bhp		6	158	120	58	7
18.	% CO_2 (Dry)		8.11	8.55	8.98	7.12	8.10
19.	% CO (Dry)		10.46	9.77	8.86	12.15	10.35
20.	% O_2 (Dry)		0.25	0.18	0.21	0.22	0.26
21.	HC-ppm (Wet)		3463	1437	1438	2715	3566
22.	NO_x-ppm (Wet)		42	188	195	60	41
23.	CO_2-lb/hr		13.6	136.1	104.0	53.6	13.4
24.	CO-lb/hr		11.1	99 0	65.3	58.3	10.9
25.	O_2-lb/hr		0.30	2.08	1.77	1.21	0.31
26.	HC-lb/hr		0.235	0.940	0.695	0.835	0.238
27.	NO_x-lb/hr		0.005	0.230	0.176	0.034	0.005
28.	CO-lb/Mode		2.230	0.495	5.443	5.826	0.725
29.	HC-lb/Mode		0.0470	0.0047	0.0579	0.0835	0.0158
30.	NO_x-lb/Mode		0.0011	0.0012	0.0147	0.0034	0.0003

TABLE C-5. AVCO LYCOMING 0-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #5- (NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

	Run No.	105	106	107	108	109
	Parameter / Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1.	Act. Baro. - inHgA	29.95	29.95	29.95	29.95	29.95
2.	Spec. Hum. - lb/lb	0.0030	0.0030	0.0030	0.0030	0.0030
3.	Induct. Air Temp.-°F	84	92	88	87	84
4.	Cooling Air Temp.-°F	92	92	85	86	85
5.	Induct. Air Press.-inHgA	29.94	30.58	30.62	30.38	29.93
6.	Engine Speed - RPM	1200	2700	2430	2350	1200
7.	Manifold Air Press.-inHgA	10.3	28.7	26.0	18.0	10.3
8.	Induct. Air Density-lb/ft^3	0.0729	0.0734	0.0741	0.0736	0.0729
9.	Fuel Flow, W_f-lb/h	8.7	87.0	64.0	43.0	9.0
10.	Airflow, W_a-lb/h	103.5	1015.0	734.0	429.0	105.9
11.	F/A (Measured) = 9 / 10	0.0841	0.0857	0.0872	0.1002	0.0850
12.	Max. Cht - °F	373	475	444	328	365
13.	Avg. Cht - °F	367	449	424	322	356
14.	Min. Cht - °F	355	414	407	314	339
15.	EGT - °F	573	1270	1203	1029	586
16.	Torque, lb-ft	27	300	248	118	28
17.	Obs. Bhp	6	154	115	53	6
18.	% CO_2 (Dry)	8.00	7.99	8.59	6.58	7.82
19.	% CO (Dry)	10.29	10.45	9.34	12.66	10.61
20.	% O_2 (Dry)	0.31	0.23	0.25	0.27	0.32
21.	HC-ppm (Wet)	3708	1596	1617	3381	4122
22.	NO_x-ppm (Wet)	39	120	145	39	33
23.	CO_2-lb/hr	13.0	127.3	97.3	45.8	13.0
24.	CO-lb/hr	10.6	106 0	67.4	56.1	11.2
25.	O_2-lb/hr	0.36	2.67	2.06	1.37	0.39
26.	HC-lb/hr	0.244	1.04	0.764	0.977	0.279
27.	NO_x-lb/hr	0.005	0.146	0.128	0.021	0.004
28.	CO-lb/Mode	2.123	0.530	5.613	5.614	0.750
29.	HC-lb/Mode	0.0489	0.0052	0.0636	0.0977	0.0186
30.	NO_x-lb/Mode	0.0010	0.0007	0.0107	0.0021	0.0003

TABLE C-6. AVCO LYCOMING 0-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-TAKEOFF MODE-SPARK SETTING 25° BTC

	Run No.	6	7	8	9	10
Parameter	Mode	Takeoff	Takeoff	Takeoff	Takeoff	Take off
1. Act. Baro. - inHgA		30.16	30.16	30.16	30.16	30.16
2. Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030	0.0030
3. Induct. Air Temp.-°F		37	37	36	36	35
4. Cooling Air Temp.-°F		30	30	29	30	30
5. Induct. Air Press.-inHgA		30.54	30.54	30.54	30.55	30.54
6. Engine Speed - RPM		2700	2700	2700	2700	2700
7. Manifold Air Press.-inHgA		28.6	28.6	28.6	28.7	28.7
8. Induct. Air Density-lb/ft^3		0.0814	0.0814	0.0816	0.0816	0.0818
9. Fuel Flow, W_f-lb/h		87.0	82.0	77.0	72.0	67.0
10. Airflow, W_a-lb/h		1050.0	1038.0	1042.0	1039.0	1040.0
11. F/A (Measured) = 9 / 10		0.0829	0.0790	0.0739	0.0693	0.0644
12. Max. Cht - °F		447	461	473	482	486
13. Avg. Cht - °F		422	436	452	464	466
14. Min. Cht - °F		388	406	432	448	454
15. EGT - °F		1301	1331	1379	1426	1474
16. Torque, lb-ft		322	325	326	325	321
17. Obs. Bhp		166	167	168	167	165
18. % CO_2 (Dry)		8.74	9.63	10.83	12.06	13.08
19. % CO (Dry)		9.28	7.78	5.67	3.74	1.81
20. % O_2 (Dry)		0.22	0.20	0.20	0.19	0.47
21. HC-ppm (Wet)		1385	1251	1059	924	653
22. NO_x-ppm (Wet)		188	302	568	1109	1605
23. CO_2-lb/hr		141.8	151.2	166.3	181.1	193.4
24. CO-lb/hr		95.8	77 8	55.4	35.7	17.0
25. O_2-lb/hr		2.60	2.28	2.23	2.07	5.05
26. HC-lb/hr		0.922	0.811	0.677	0.578	0.404
27. NO_x-lb/hr		0.234	0.366	0.679	1.297	1.858
28. CO-lb/Mode		0.479	0.389	0.277	0.179	0.085
29. HC-lb/Mode		0.0046	0.0041	0.0034	0.0029	0.0020
30. NO_x-lb/Mode		0.0012	0.0018	0.0034	0.0065	0.0093

TABLE C-7. AVCO LYCOMING 0-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-CLIMB MODE-SPARK SETTING 25° BTC

	Run No.	11	12	13	14	15
Parameter	Mode	Climb	Climb	Climb	Climb	Climb
1. Act. Baro. - inHgA		30.16	30.16	30.16	30.16	30.17
2. Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030	0.0030
3. Induct. Air Temp.-°F		35	34	35	35	34
4. Cooling Air Temp.-°F		30	29	29	29	29
5. Induct. Air Press.-inHgA		30.56	30.56	30.56	30.56	30.58
6. Engine Speed - RPM		2430	2430	2430	2430	2430
7. Manifold Air Press.-inHgA		26.0	26.0	26.0	26.0	26.0
8. Induct. Air Density-lb/ft^3		0.0818	0.0820	0.0818	0.0818	0.0820
9. Fuel Flow, W_f-lb/h		64.0	60.0	56.0	52.0	48.0
10. Airflow, W_a-lb/h		769.0	762.0	755.0	753.0	753.0
11. F/A (Measured) = 9 / 10		0.0832	0.0787	0.0742	0.0691	0.0638
12. Max. Cht - °F		411	418	429	436	433
13. Avg. Cht - °F		400	410	421	427	422
14. Min. Cht - °F		387	401	414	419	411
15. EGT - °F		1223	1265	1318	1370	1401
16. Torque, lb-ft		263	270	268	264	257
17. Obs. Bhp		122	125	124	122	119
18. % CO_2 (Dry)		9.24	10.47	11.93	13.11	13.68
19. % CO (Dry)		8.44	6.33	3.93	1.96	0.58
20. % O_2 (Dry)		0.25	0.23	0.24	0.30	0.68
21. HC-ppm (Wet)		1663	1392	1112	828	511
22. NO_x-ppm (Wet)		206	400	876	1506	1812
23. CO_2-lb/hr		108.6	118.5	130.6	140.5	145.2
24. CO-lb/hr		63.1	45 6	27.4	13.4	3.92
25. O_2-lb/hr		2.13	1.89	1.91	2.34	5.25
26. HC-lb/hr		0.813	0.663	0.515	0.374	0.229
27. NO_x-lb/hr		0.188	0.356	0.759	1.277	1.518
28. CO-lb/Mode		5.260	3.799	2.281	1.114	0.327
29. HC-lb/Mode		0.0677	0.0552	0.0429	0.0313	0.0191
30. NO_x-lb/Mode		0.0157	0.0297	0.0632	0.1064	0.1265

TABLE C-8. AVCO LYCOMING O-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-APPROACH MODE-SPARK SETTING 25° BTC

	Run No.	16	17	18	19	20
Parameter	Mode	Approach	Approach	Approach	Approach	Approach
1. Act. Baro. - inHgA		30.17	30.17	30.17	30.17	30.19
2. Spec. Hum. - lb/lb		0.0010	0.0010	0.0010	0.0010	0.0010
3. Induct. Air Temp.-°F		34	34	34	34	34
4. Cooling Air Temp.-°F		29	28	29	29	29
5. Induct. Air Press.-inHgA		30.32	30.32	30.32	30.33	30.35
6. Engine Speed - RPM		2350	2350	2350	2350	2350
7. Manifold Air Press.-inHgA		18.0	18.0	18.0	18.0	18.0
8. Induct. Air Density-lb/ft^3		0.0813	0.0813	0.0813	0.0814	0.0814
9. Fuel Flow, W_f-lb/h		44.0	41.0	38.0	35.0	32.0
10. Airflow, W_a-lb/h		462.0	463.0	464.0	453.0	451.0
11. F/A (Measured) = 9 / 10		0.0952	0.0886	0.0819	0.0773	0.0710
12. Max. Cht - °F		314	321	329	336	343
13. Avg. Cht - °F		302	312	324	333	339
14. Min. Cht - °F		294	305	317	328	334
15. EGT - °F		1039	1063	1096	1132	1203
16. Torque, lb-ft		133	137	142	141	139
17. Obs. Bhp		59.5	61.3	63.5	63.1	62.2
18. % CO_2 (Dry)		7.23	8.40	9.79	11.09	12.75
19. % CO (Dry)		11.81	9.83	7.50	5.29	2.52
20. % O_2 (Dry)		0.22	0.23	0.22	0.22	0.37
21. HC-ppm (Wet)		2823	2016	1649	1377	929
22. NO_x-ppm (Wet)		67	122	242	436	827
23. CO_2-lb/hr		53.6	60.6	68.6	74.0	82.5
24. CO-lb/hr		55.8	45 1	33.4	22.5	10.4
25. O_2-lb/hr		1.19	1.21	1.12	1.07	1.74
26. HC-lb/hr		0.865	0.604	0.484	0.388	0.254
27. NO_x-lb/hr		0.038	0.068	0.133	0.230	0.423
28. CO-lb/Mode		5.576	4.511	3.345	2.246	1.038
29. HC-lb/Mode		0.0865	0.0604	0.0484	0.0388	0.0254
30. NO_x-lb/Mode		0.0038	0.0068	0.0133	0.0230	0.0423

TABLE C-9. AVCO LYCOMING 0-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-TAXI MODE-SPARK SETTING 25° BTC (Time in Mode 16.0 Minutes)

	Parameter	Run No.	21	22	23	24	25
		Mode	Taxi	Taxi	Taxi	Taxi	Taxi
1.	Act. Baro. - inHgA		30.16	30.16	30.16	30.16	30.16
2.	Spec. Hum. - lb/lb		0.0020	0.0020	0.0020	0.0020	0.0020
3.	Induct. Air Temp.-°F		37	37	37	37	36
4.	Cooling Air Temp.-°F		36	36	36	36	36
5.	Induct. Air Press.-inHgA		30.57	30.58	30.57	30.58	30.58
6.	Engine Speed - RPM		1200	1200	1200	1200	1200
7.	Manifold Air Press.-inHgA		10.2	10.1	10.1	10.0	10.0
8.	Induct. Air Density-lb/ft^3		0.0815	0.0815	0.0815	0.0815	0.0817
9.	Fuel Flow, W_f-lb/h		8.8	8.3	7.8	7.3	6.8
10.	Airflow, W_a-lb/h		106.1	105.2	104.4	103.5	105.4
11.	F/A (Measured) = 9 / 10		0.0829	0.0790	0.0747	0.0705	0.0645
12.	Max. Cht ~ °F		355	375	372	389	394
13.	Avg. Cht ~ °F		342	368	361	377	378
14.	Min. Cht ~ °F		331	360	351	371	363
15.	EGT - °F		521	511	509	518	535
16.	Torque, lb-ft		30	30	31	32	33
17.	Obs. Bhp		6.9	6.9	7.1	7.3	7.5
18.	% CO_2 (Dry)		7.12	7.56	8.04	8.89	10.16
19.	% CO (Dry)		8.44	7.82	6.84	5.47	3.50
20.	% O_2 (Dry)		3.16	3.27	3.32	3.39	3.41
21.	HC-ppm (Wet)		3135	2033	2320	1942	1482
22.	NO_x-ppm (Wet)		38	13	53	66	89
23.	CO_2-lb/hr		11.7	12.2	12.7	13.7	15.7
24.	CO-lb/hr		8.80	8.04	6.89	5.38	3.44
25.	O_2-lb/hr		3.76	3.84	3.82	3.81	3.83
26.	HC-lb/hr		0.211	0.134	0.149	0.124	0.092
27.	NO_x-lb/hr		0.005	0.002	0.006	0.008	0.010
28.	CO-lb/Mode		2.347	2.143	1.837	1.435	0.917
29.	HC-lb/Mode		0.0562	0.0357	0.0397	0.0324	0.0246
30.	NO_x-lb/Mode		0.0013	0.0004	0.0017	0.0021	0.0027

TABLE C-10. AVCO LYCOMING 0-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-TAKEOFF MODE-SPARK SETTING 25° BTC

	Run No.	85	86	87	88	89
Parameter	Mode	Takeoff	Takeoff	Takeoff	Takeoff	Takeoff
1. Act. Baro. - inHgA		30.45	30.45	30.45	30.45	30.45
2. Spec. Hum. - lb/lb		0.0010	0.0010	0.0010	0.0010	0.0010
3. Induct. Air Temp.-°F		75	75	73	73	75
4. Cooling Air Temp.-°F		80	77	72	72	78
5. Induct. Air Press.-inHgA		31.01	31.10	30.91	30.93	30.92
6. Engine Speed - RPM		2700	2700	2700	2700	2700
7. Manifold Air Press.-inHgA		28.8	28.8	28.8	28.8	28.8
8. Induct. Air Density-lb/ft^3		0.0768	0.0770	0.0769	0.0769	0.0763
9. Fuel Flow, W_f-lb/h		87.0	82.0	77.0	72.0	67.0
10. Airflow, W_a-lb/h		1018.0	1031.0	1023.0	1028.0	1016.0
11. F/A (Measured) = 9 / 10		0.0855	0.0795	0.0753	0.0700	0.0659
12. Max. Cht - °F		473	482	499	510	515
13. Avg. Cht - °F		448	460	476	490	498
14. Min. Cht - °F		414	431	455	471	487
15. EGT - °F		1291	1322	1367	1410	1461
16. Torque, lb-ft		312	316	316	313	310
17. Obs. Bhp		160	162	162	161	159
18. % CO_2 (Dry)		8.66	9.53	10.58	11.64	12.93
19. % CO (Dry)		9.42	7.85	6.08	4.32	2.10
20. % O_2 (Dry)		0.20	0.19	0.20	0.20	0.27
21. HC-ppm (Wet)		1438	1300	1127	997	772
22. NO_x-ppm (Wet)		181	293	517	956	1623
23. CO_2-lb/hr		137.0	149.0	160.5	174.2	187.3
24. CO-lb/hr		94.8	78.1	58.7	41.1	19.4
25. O_2-lb/hr		2.30	2.16	2.20	2.18	2.84
26. HC-lb/hr		0.937	0.840	0.710	0.618	0.467
27. NO_x-lb/hr		0.211	0.354	0.609	1.109	1.838
28. CO-lb/Mode		0.474	0.391	0.294	0.206	0.097
29. HC-lb/Mode		0.0047	0.0042	0.0036	0.0031	0.0023
30. NO_x-lb/Mode		0.0011	0.0018	0.0030	0.0055	0.0092

TABLE C-11. AVCO LYCOMING 0-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-CLIMB MODE-SPARK SETTING 25° BTC

	Run No.	90	91	92	93	94
Parameter	**Mode**	Climb	Climb	Climb	Climb	Climb
1. Act. Baro. - inHgA		30.45	30.45	30.45	30.45	30.44
2. Spec. Hum. - lb/lb		0.0010	0.0010	0.0010	0.0010	0.0010
3. Induct. Air Temp.-°F		73	71	67	67	68
4. Cooling Air Temp.-°F		74	70	62	65	66
5. Induct. Air Press.-inHgA		31.19	31.20	32.21	31.20	31.20
6. Engine Speed - RPM		2430	2430	2430	2430	2430
7. Manifold Air Press.-inHgA		26.0	26.0	26.0	26.0	26.0
8. Induct. Air Density-lb/ft^3		0.0776	0.0779	0.0785	0.0785	0.0785
9. Fuel Flow, W_f-lb/h		65.0	61.0	57.0	53.0	49.0
10. Airflow, W_a-lb/h		767.0	759.0	758.0	752.0	752.0
11. F/A (Measured) = 9 / 10		0.0847	0.0804	0.0752	0.0705	0.0652
12. Max. Cht - °F		434	443	437	440	447
13. Avg. Cht - °F		416	426	430	433	437
14. Min. Cht - °F		402	413	422	427	429
15. EGT - °F		1208	1243	1279	1322	1371
16. Torque, lb-ft		254	256	257	258	255
17. Obs. Bhp		118	118	119	119	118
18. % CO_2 (Dry)		8.95	9.98	11.10	12.17	13.20
19. % CO (Dry)		8.77	7.04	5.17	3.37	1.54
20. % O_2 (Dry)		0.21	0.22	0.21	0.23	0.43
21. HC-ppm (Wet)		1603	1394	1221	1022	702
22. NO_x-ppm (Wet)		173	317	559	1061	1601
23. CO_2-lb/hr		105.4	113.8	123.6	131.9	141.0
24. CO-lb/hr		65.7	51.1	36.7	23.2	10.5
25. O_2-lb/hr		1.80	1.82	1.70	1.81	3.34
26. HC-lb/hr		0.785	0.664	0.570	0.465	0.314
27. NO_x-lb/hr		0.158	0.283	0.488	0.902	1.341
28. CO-lb/Mode		5.476	4.257	3.055	1.937	0.873
29. HC-lb/Mode		0.0654	0.0554	0.0475	0.0387	0.0262
30. NO_x-lb/Mode		0.0132	0.0236	0.0407	0.0752	0.1117

TABLE C-12. AVCO LYCOMING 0-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-APPROACH MODE-SPARK SETTING 25° BTC

Parameter	Run No.	95	96	97	98	99
	Mode	Approach	Approach	Approach	Approach	Approach
1. Act. Baro. - inHgA		29.97	29.97	29.97	29.97	29.95
2. Spec. Hum. - lb/lb		0.0020	0.0020	0.0020	0.0020	0.0030
3. Induct. Air Temp.-°F		80	83	84	87	89
4. Cooling Air Temp.-°F		92	92	91	93	94
5. Induct. Air Press.-inHgA		30.38	30.38	30.38	30.38	30.37
6. Engine Speed - RPM		2320	2350	2350	2350	2350
7. Manifold Air Press.-inHgA		18.0	18.1	18.1	18.0	18.0
8. Induct. Air Density-lb/ft^3		0.0746	0.0741	0.0740	0.0736	0.0733
9. Fuel Flow, W_f-lb/h		43.0	40.0	37.0	34.0	31.0
10. Airflow, W_a-lb/h		437.0	438.0	439.0	431.0	426.0
11. F/A (Measured) = 9 / 10		0.0984	0.0913	0.0843	0.0789	0.0728
12. Max. Cht - °F		332	343	353	365	376
13. Avg. Cht - °F		327	338	350	361	370
14. Min. Cht - °F		320	332	347	355	365
15. EGT - °F		1037	1052	1085	1124	1170
16. Torque, lb-ft		120	122	127	128	127
17. Obs. Bhp		53	56	57	57	57
18. % CO_2 (Dry)		6.73	7.59	8.95	10.40	11.86
19. % CO (Dry)		12.44	11.04	8.71	6.28	3.75
20. % O_2 (Dry)		0.23	0.24	0.24	0.24	0.32
21. HC-ppm (Wet)		3254	2232	1744	1377	1026
22. NO_x-ppm (Wet)		46	80	154	337	642
23. CO_2-lb/hr		47.7	52.7	60.2	66.5	73.1
24. CO-lb/hr		56.1	48.8	37.3	25.6	14.7
25. O_2-lb/hr		1.18	1.21	1.17	1.12	1.43
26. HC-lb/hr		0.953	0.639	0.488	0.371	0.267
27. NO_x-lb/hr		0.025	0.043	0.081	0.170	1.312
28. CO-lb/Mode		5.609	4.881	3.728	2.557	1.471
29. HC-lb/Mode		0.0953	0.0639	0.0488	0.0371	0.0267
30. NO_x-lb/Mode		0.0025	0.0043	0.0081	0.0170	0.0312

TABLE C-13. AVCO LYCOMING 0-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-TAXI MODE-SPARK SETTING 25° BTC (Time in Mode 16.0-Minutes)

Parameter	Run No. / Mode	100 Taxi	101 Taxi	102 Taxi	103 Taxi	104 Taxi
1.	Act. Baro. - inHgA	30.45	30.45	30.45	30.45	30.45
2.	Spec. Hum. - lb/lb	0.0010	0.0010	0.0010	0.0010	0.0010
3.	Induct. Air Temp.-°F	75	71	70	69	71
4.	Cooling Air Temp.-°F	95	101	100	97	99
5.	Induct. Air Press.-inHgA	30.43	30.43	30.43	30.43	30.43
6.	Engine Speed - RPM	1200	1200	1200	1200	1200
7.	Manifold Air Press.-inHgA	9.0	9.9	9.9	9.8	9.9
8.	Induct. Air Density-lb/ft^3	0.0754	0.0759	0.0761	0.0762	0.0759
9.	Fuel Flow, W_f-lb/h	8.8	8.3	7.7	7.3	6.8
10.	Airflow, W_a-lb/h	103.7	103.2	103.4	99.2	100.7
11.	F/A (Measured) = 9 / 10	0.0849	0.0804	0.0745	0.0736	0.0675
12.	Max. Cht - °F	362	368	378	393	400
13.	Avg. Cht - °F	352	355	363	380	378
14.	Min. Cht - °F	343	337	344	365	352
15.	EGT - °F	560	539	546	545	585
16.	Torque, lb-ft	28	27	27	26	26
17.	Obs. Bhp	6.4	6.2	6.2	5.9	5.9
18.	% CO_2 (Dry)	8.13	8.53	10.02	10.18	11.85
19.	% CO (Dry)	10.31	9.72	7.16	6.92	4.07
20.	% O_2 (Dry)	0.29	0.28	0.29	0.25	0.25
21.	HC-ppm (Wet)	3763	3163	2058	2135	1484
22.	NO_x-ppm (Wet)	44	49	77	77	116
23.	CO_2-lb/hr	13.3	13.7	15.6	15.2	17.4
24.	CO-lb/hr	10.7	9.95	7.10	6.57	3.80
25.	O_2-lb/hr	0.342	0.326	0.330	0.272	0.266
26.	HC-lb/hr	0.249	0.6205	0.131	0.129	0.089
27.	NO_x-lb/hr	0.005	0.006	0.009	0.009	1.013
28.	CO-lb/Mode	2.853	2.652	1.892	1.752	1.012
29.	HC-lb/Mode	0.0664	0.0547	0.0349	0.0345	0.0238
30.	NO_x-lb/Mode	0.0014	0.0016	0.0024	0.0023	0.0035

APPENDIX D

NAFEC TEST DATA AND WORKING PLOTS FOR ANALYSIS AND EVALUATION FOR THE AVCO LYCOMING IO-320-DIAD ENGINE

LIST OF ILLUSTRATIONS

Figure		Page
D-1	Measured Performance--Avco Lycoming IO-320-DIAD Engine--Takeoff, Climb, and Approach Modes--Nominal Sea Level Air Density, ρ_i = 0.0800 lb/ft^3	D-1
D-2	Measured Performance--Avco Lycoming IO-320-DIAD Engine--Takeoff, Climb, and Approach Modes--Nominal Sea Level Air Density, ρ_i = 0.0750 lb/ft^3	D-2
D-3	Airflow as a Function of Induction Air Specific Weight for an Avco Lycoming IO-320-DIAD Engine--Nominal Sea Level Test Data	D-3
D-4	Exhaust Carbon Monoxide as a Function of Induction Air Specific Weight for Several Takeoff Constant Fuel-Flow Schedules--Avco Lycoming IO-320-DIAD Engine	D-4
D-5	Exhaust Carbon Monoxide as a Function of Induction Air Specific Weight for Several Climb Mode Constant Fuel-Flow Schedules--Avco Lycoming IO-320-DIAD Engine	D-5
D-6	Exhaust Carbon Monoxide as a Function of Induction Air Specific Weight for Several Approach Mode Constant Fuel-Flow Schedules--Avco Lycoming IO-320-DIAD Engine	D-6
D-7	Unburned Exhaust Hydrocarbons as a Function of Induction Air Specific Weight for Several Takeoff Constant Fuel-Flow Schedules--Avco Lycoming IO-320-DIAD Engine	D-7
D-8	Unburned Exhaust Hydrocarbons as a Function of Induction Air Specific Weight for Several Climb Mode Constant Fuel-Flow Schedules--Avco Lycoming IO-320-DIAD Engine	D-8
D-9	Unburned Exhaust Hydrocarbons as a Function of Induction Air Specific Weight for Several Approach Mode Constant Fuel-Flow Schedules--Avco Lycoming IO-320-DIAD Engine	D-9
D-10	Oxides of Nitrogen (NO_x) as a Function of Induction Air Specific Weight for Several Takeoff Constant Fuel-Flow Schedules--Avco Lycoming IO-320-DIAD Engine	D-10
D-11	Oxides of Nitrogen (NO_x) as a Function of Induction Air Specific Weight for Several Climb Mode Constant Fuel-Flow Schedules--Avco Lycoming IO-320-DIAD Engine	D-11

LIST OF ILLUSTRATIONS (Continued)

Figure		Page
D-12	Oxides of Nitrogen (NO_x) as a Function of Induction Air Specific Weight for Several Approach Mode Constant Fuel-Flow Schedules—Avco Lycoming IO-320-DIAD Engine	D-12
D-13	Nominal Sea Level Standard Day Emissions Characteristics for an Avco Lycoming IO-320-DIAD Engine—Carbon Monoxide	D-13
D-14	Nominal Sea Level Standard Day Emissions Charateristics for an Avco Lycoming IO-320-DIAD Engine--Unburned Hydrocarbons	D-14
D-15	Nominal Sea Level Standard Day Emissions Charateristics for an Avco Lycoming IO-320-DIAD Engine—Oxides of Nitrogen	D-15

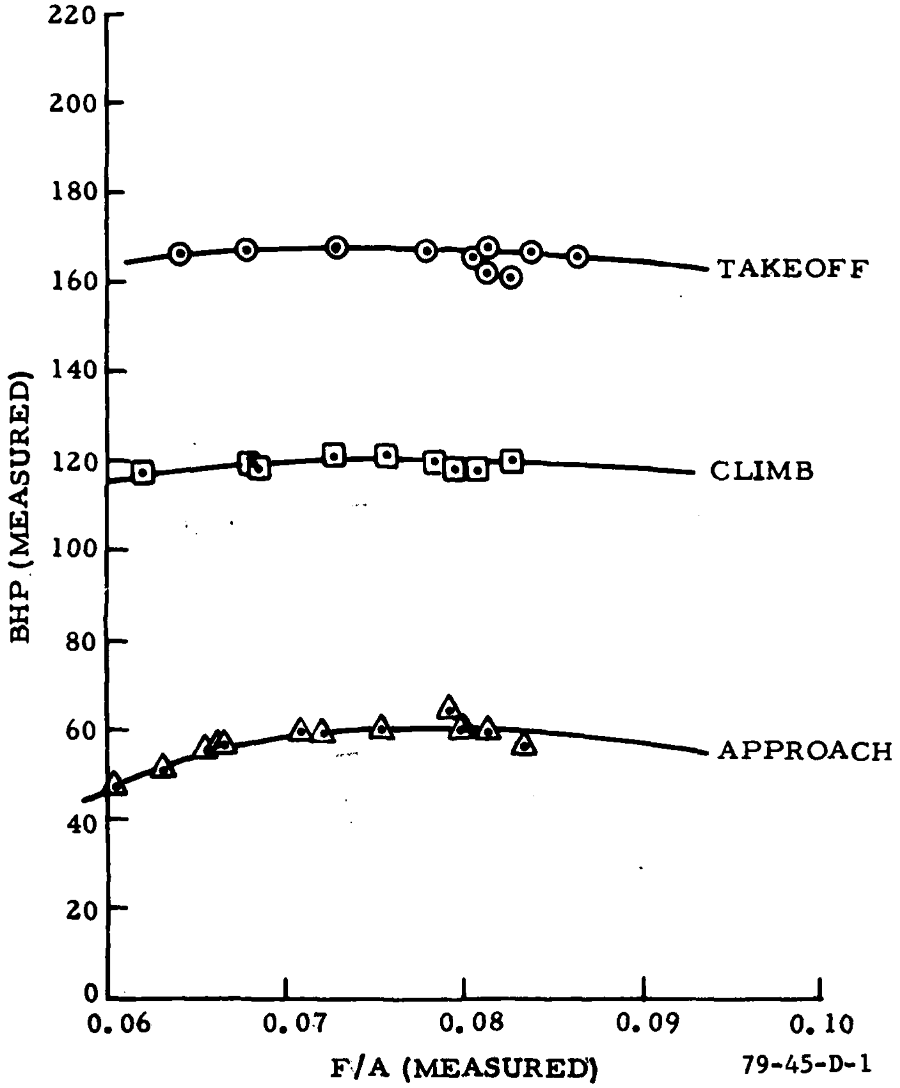


FIGURE D-1. MEASURED PERFORMANCE--AVCO LYCOMING IO-320-DIAD ENGINE--TAKEOFF, CLIMB, AND APPROACH MODES--NOMINAL SEA LEVEL AIR DENSITY, ρ_1 = 0.0800 lb/ft^3

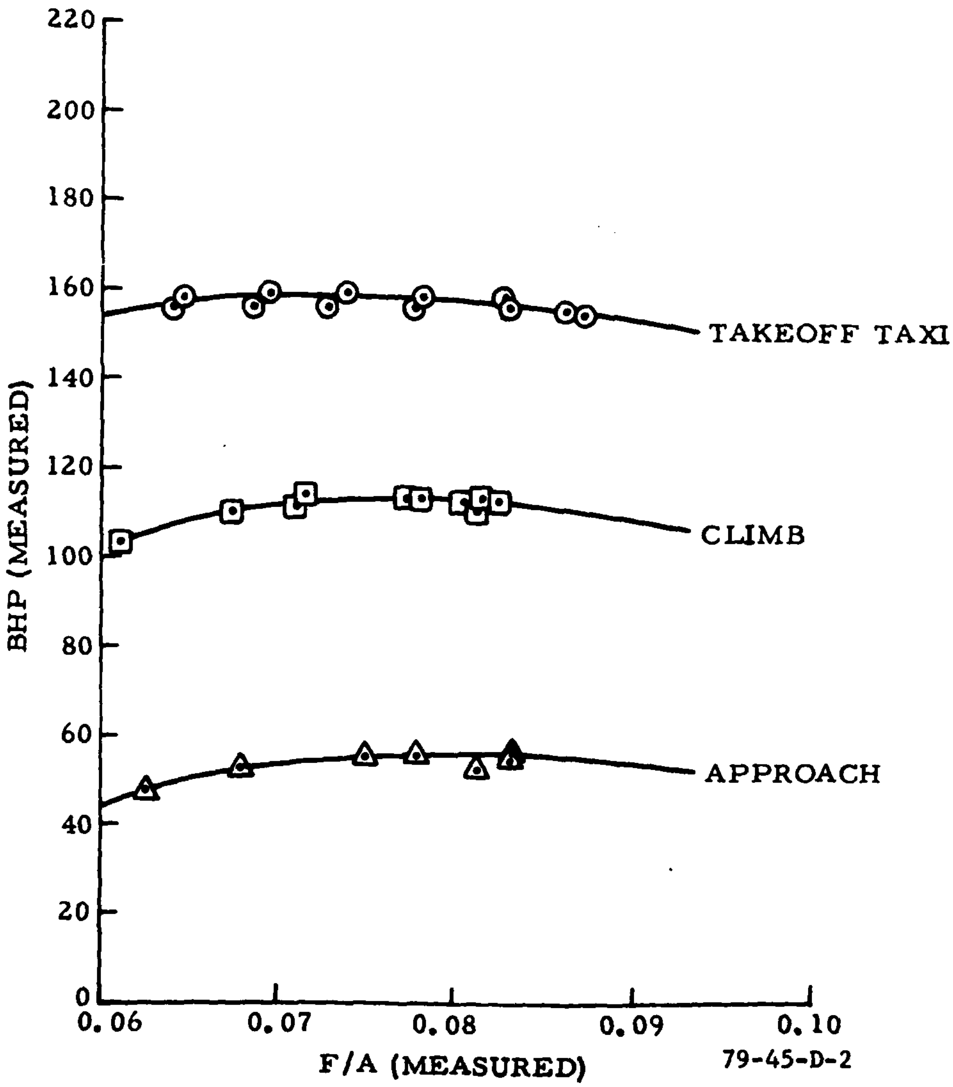


FIGURE D-2. MEASURED PERFORMANCE--AVCO LYCOMING IO-320-DIAD ENGINE--TAKEOFF, CLIMB, AND APPROACH MODES--NOMINAL SEA LEVEL AIR DENSITY, $\rho_i = 0.0750$ lb/ft^3

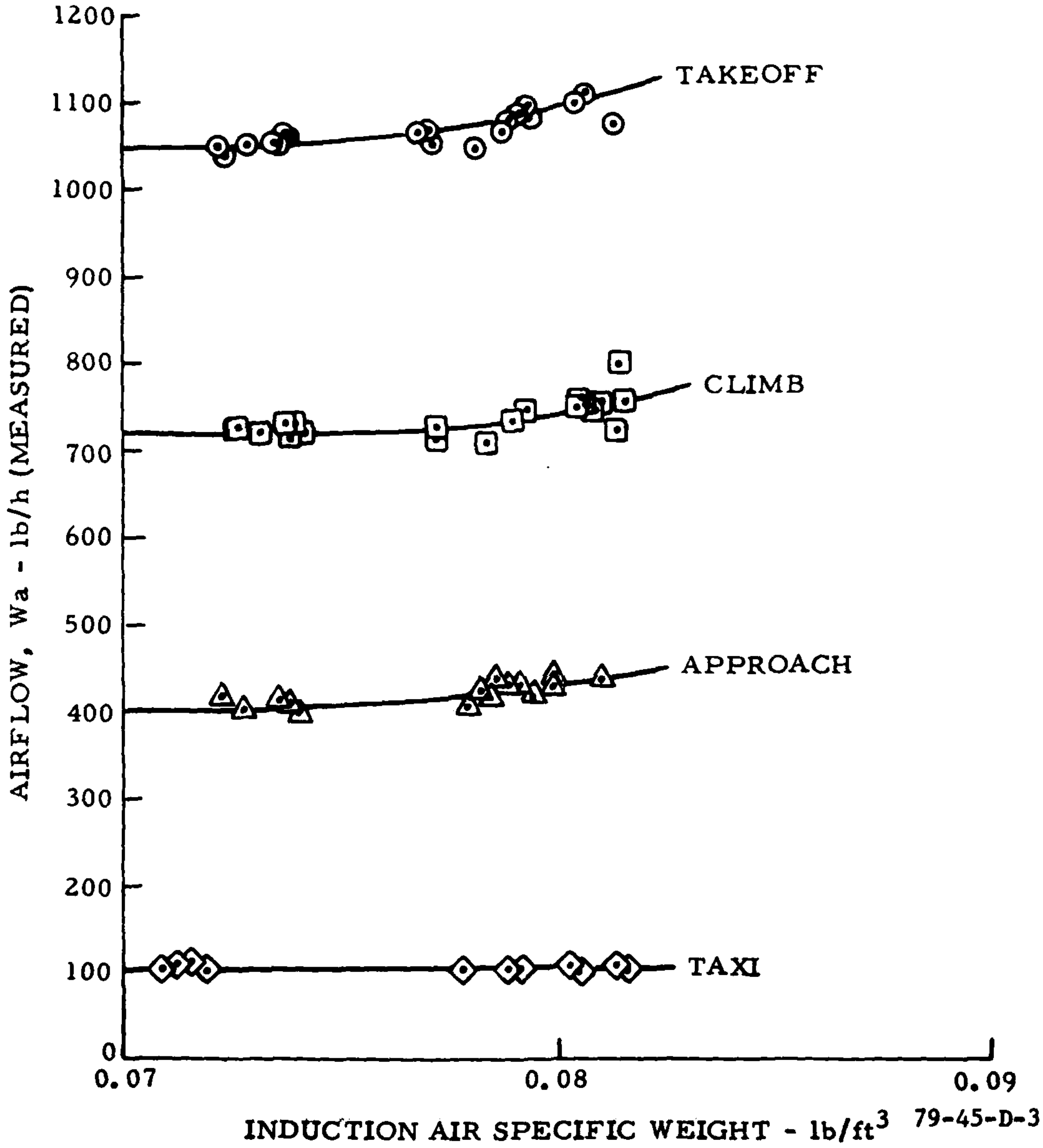


FIGURE D-3. AIRFLOW AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR AN AVCO LYCOMING IO-320-DIAD ENGINE—NOMINAL SEA LEVEL TEST DATA

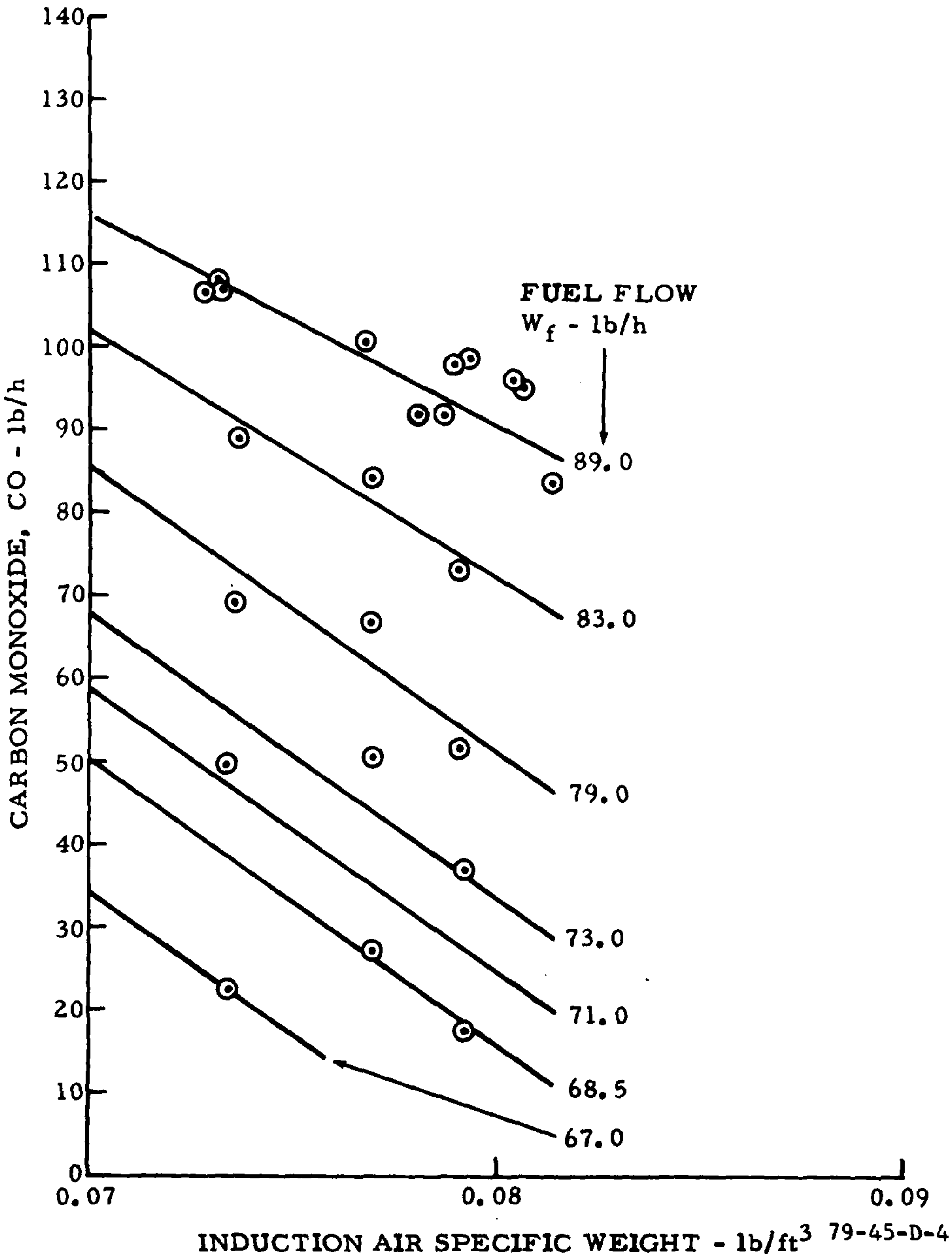


FIGURE D-4. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAKEOFF CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING IO-320-DIAD ENGINE

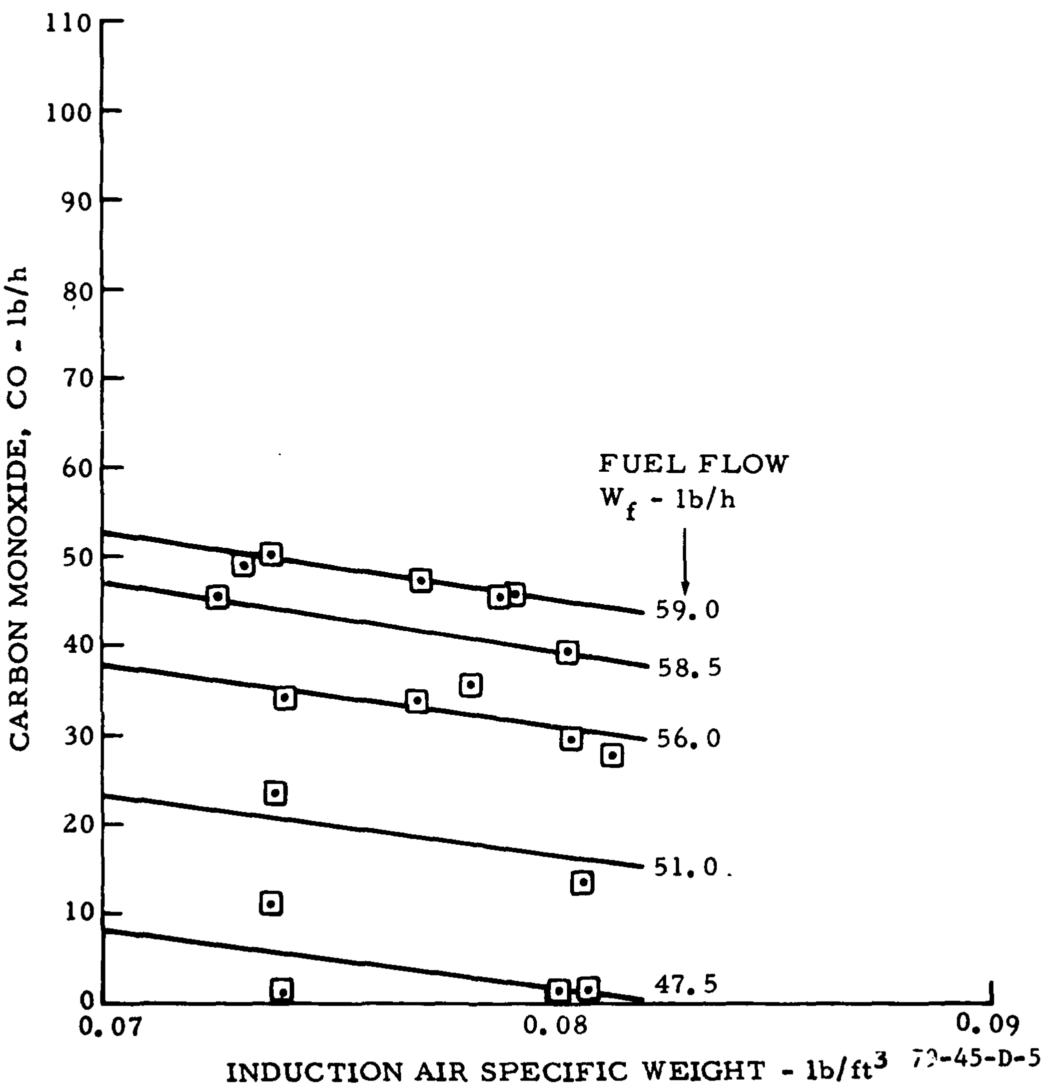


FIGURE D-5. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL CLIMB MODE CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING IO-320-DIAD ENGINE

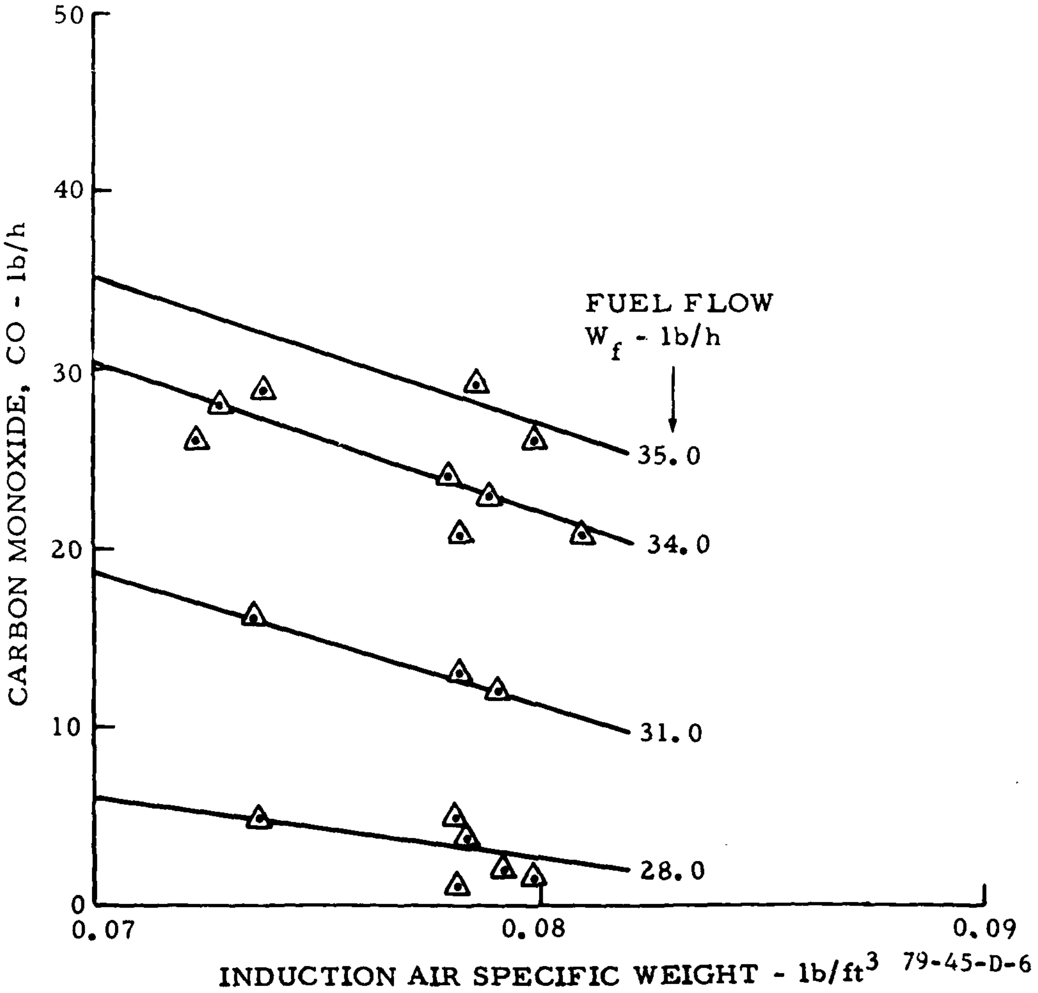
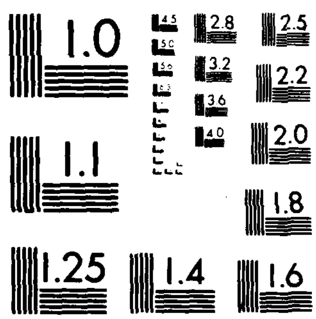


FIGURE D-6. EXHAUST CARBON MONOXIDE AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL APPROACH MODE CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING IO-320-DIAD ENGINE

AD-A084 933 NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER ATL--ETC F/G 13/2
EXHAUST EMISSIONS CHARACTERISTICS FOR A GENERAL AVIATION LIGHT---ETC(U)
APR 80 E E BECKER
UNCLASSIFIED FAA-NA-79-45 NL

2 OF 2
AD
A084933

END
DATE
FILMED
7-80
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963 A

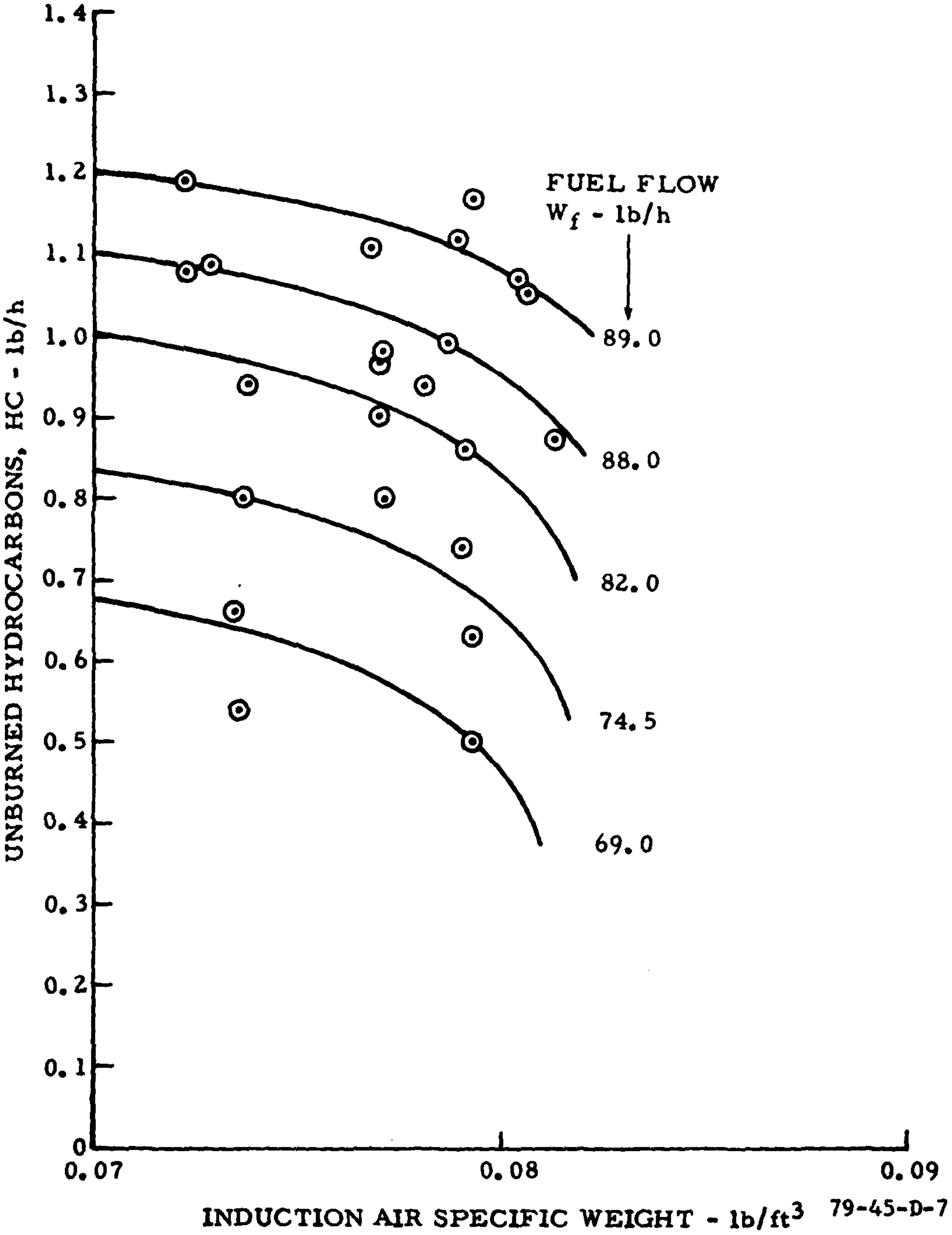


FIGURE D-7. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAKEOFF CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING IO-320-DIAD ENGINE

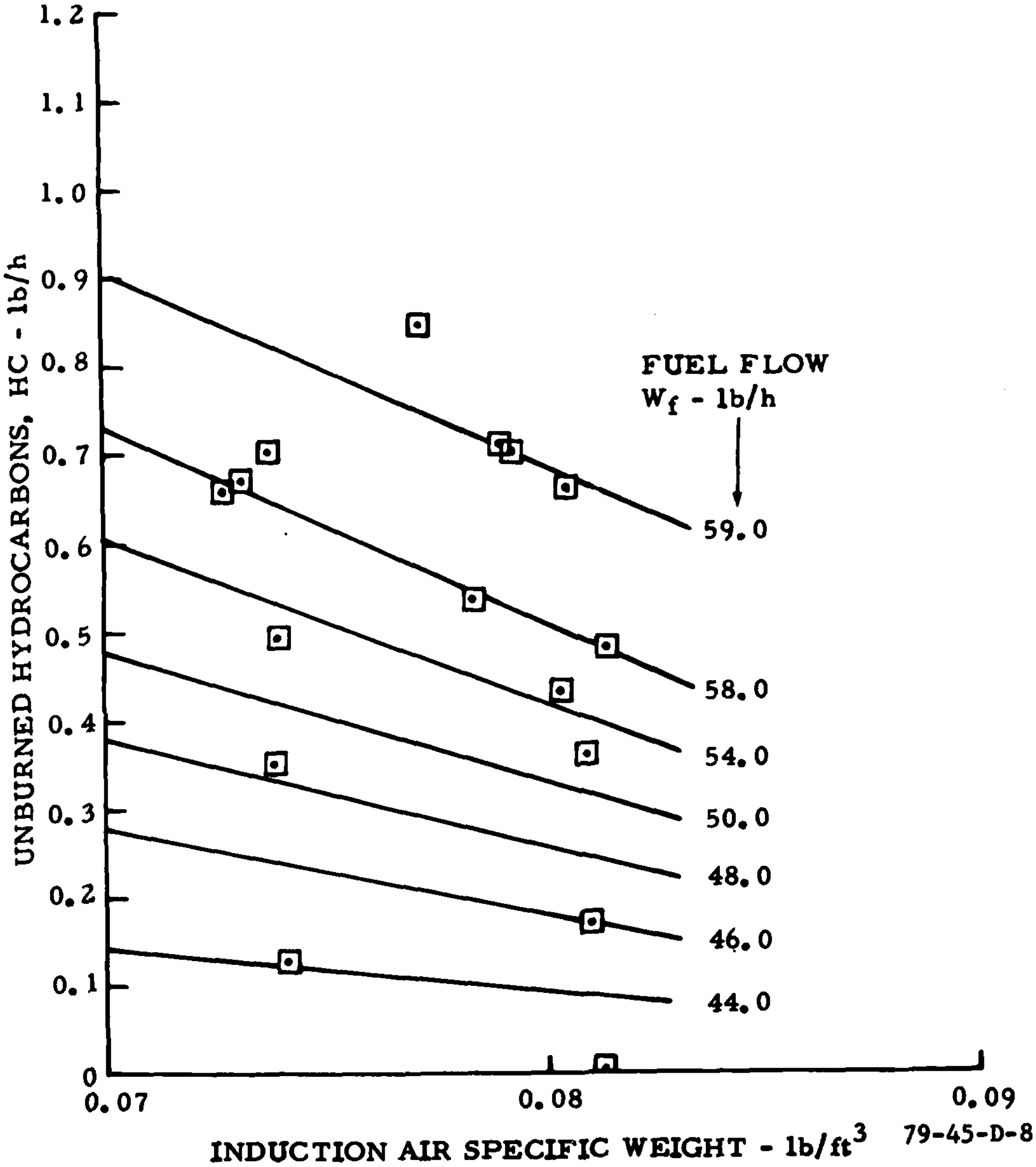


FIGURE D-8. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL CLIMB MODE CONSTANT FUEL-FLOW SCHEDULES—AVCO LYCOMING IO-320-DIAD ENGINE

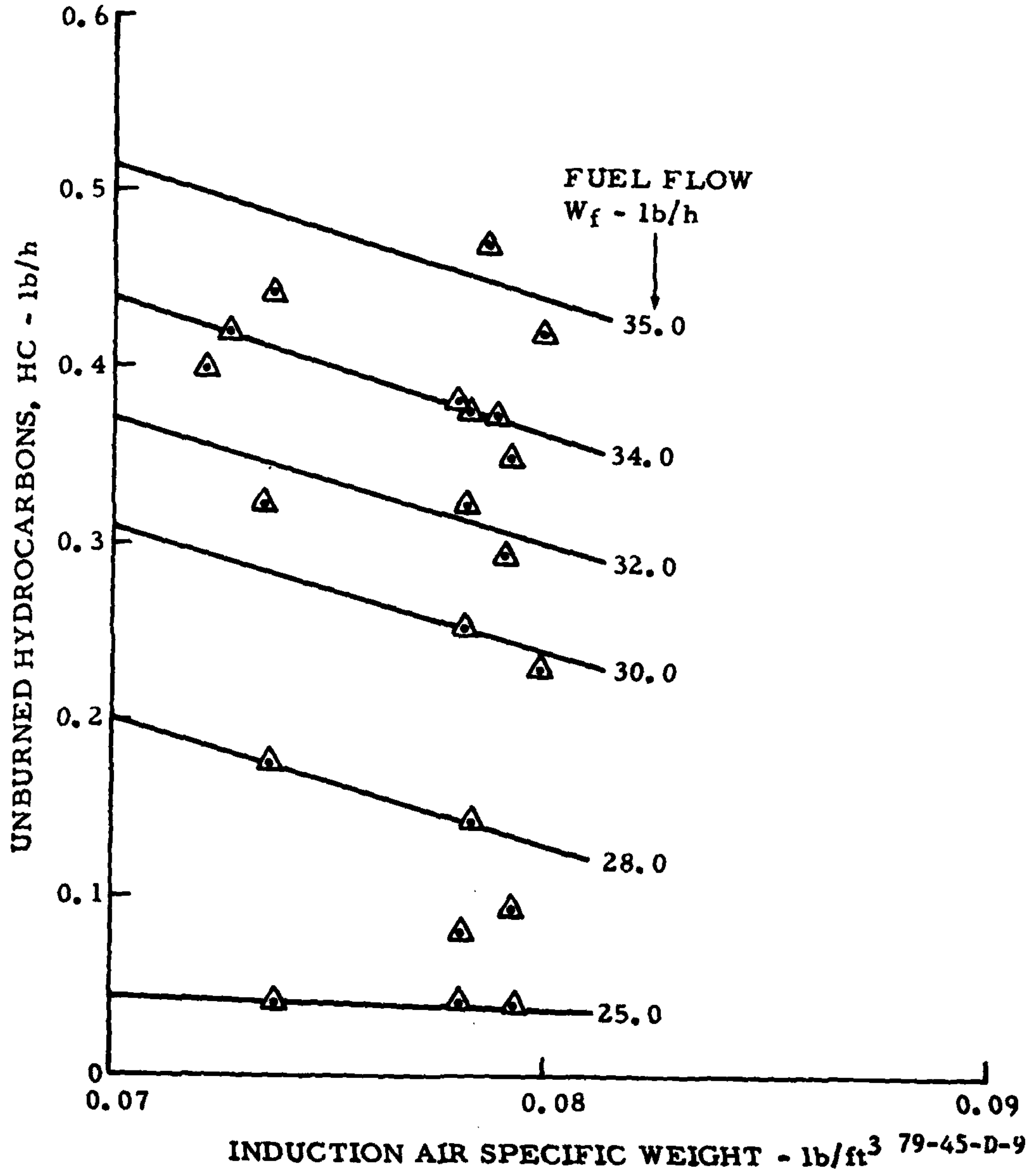


FIGURE D-9. UNBURNED EXHAUST HYDROCARBONS AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL APPROACH MODE CONSTANT FUEL-FLOW SCHEDULES—AVCO LYCOMING IO-320-DIAD ENGINE

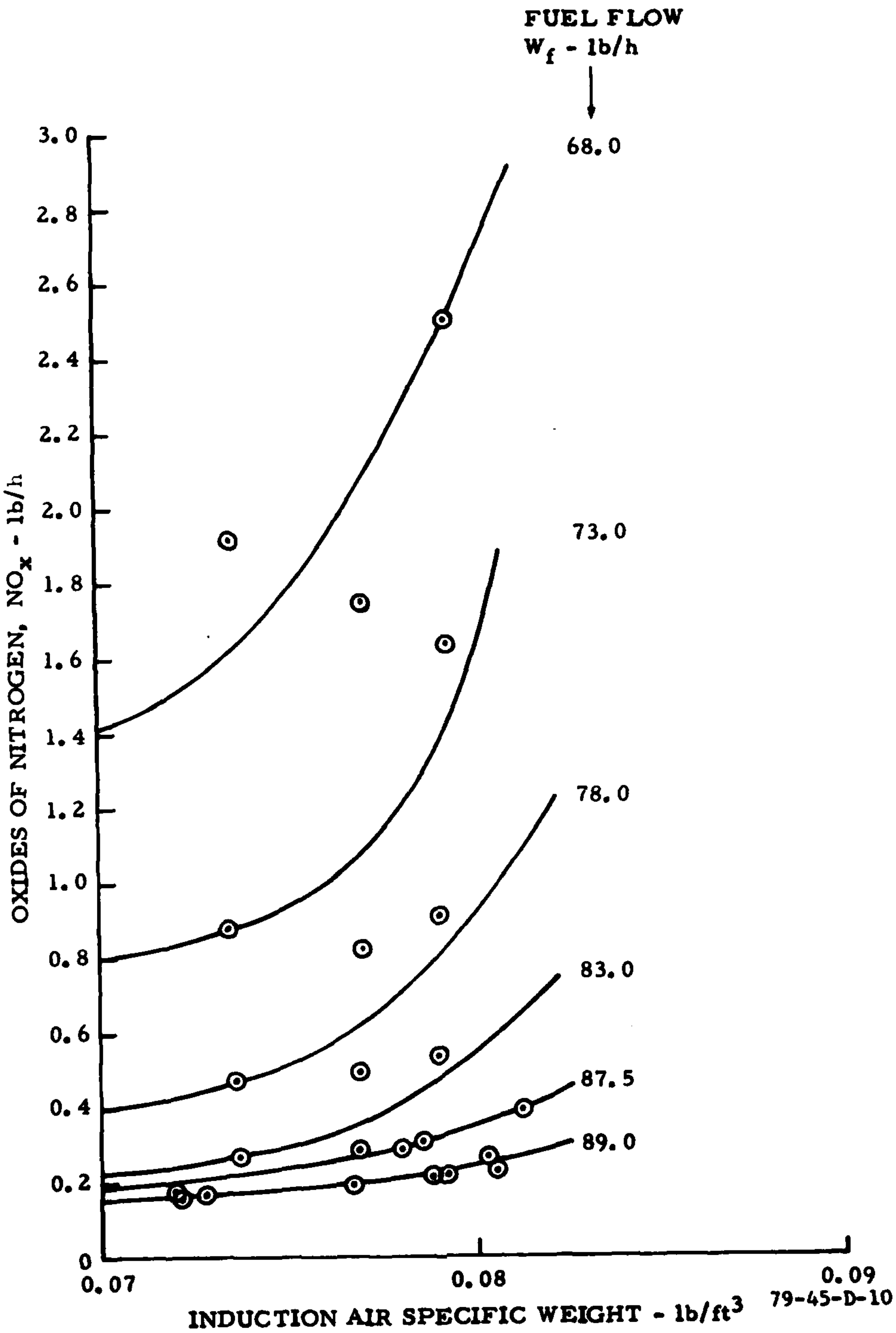


FIGURE D-10. OXIDES OF NITROGEN (NO_x) AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL TAKEOFF CONSTANT FUEL-FLOW SCHEDULES—AVCO LYCOMING IO-320-DIAD ENGINE

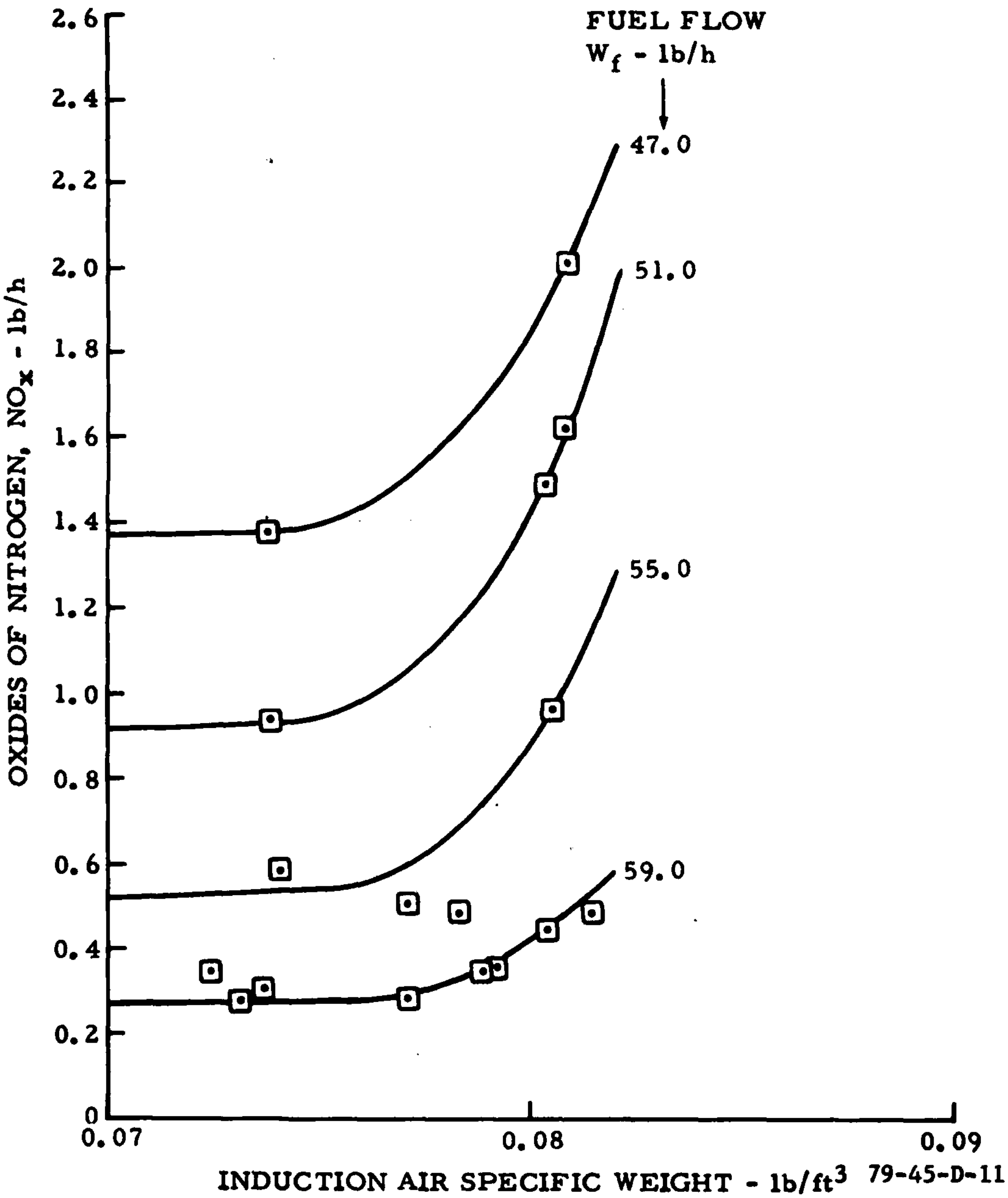


FIGURE D-11. OXIDES OF NITROGEN (NO_x) AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL CLIMB MODE CONSTANT FUEL-FLOW SCHEDULES--AVCO LYCOMING IO-320-DIAD ENGINE

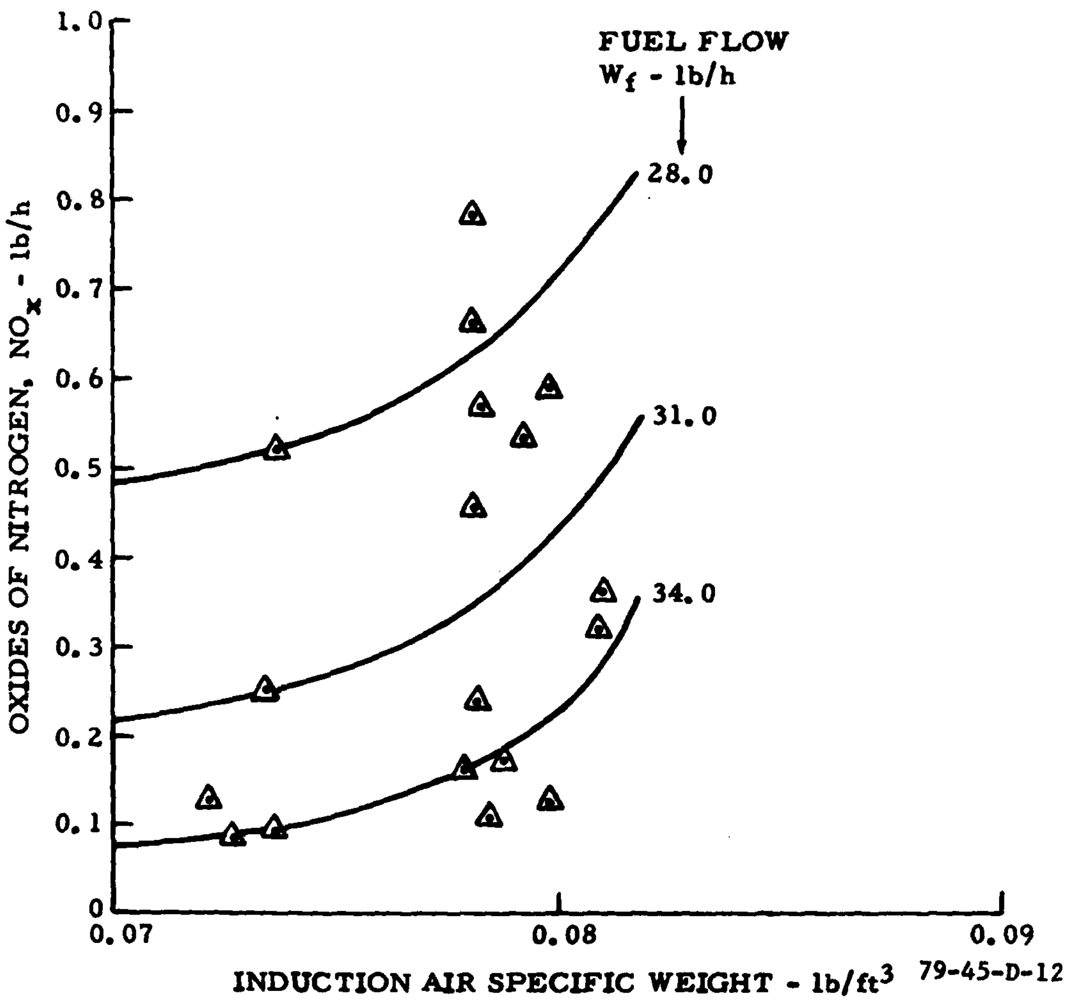


FIGURE D-12. OXIDES OF NITROGEN (NO_x) AS A FUNCTION OF INDUCTION AIR SPECIFIC WEIGHT FOR SEVERAL APPROACH MODE CONSTANT FUEL-FLOW SCHEDULES—AVCO LYCOMING IO-320-DIAD ENGINE

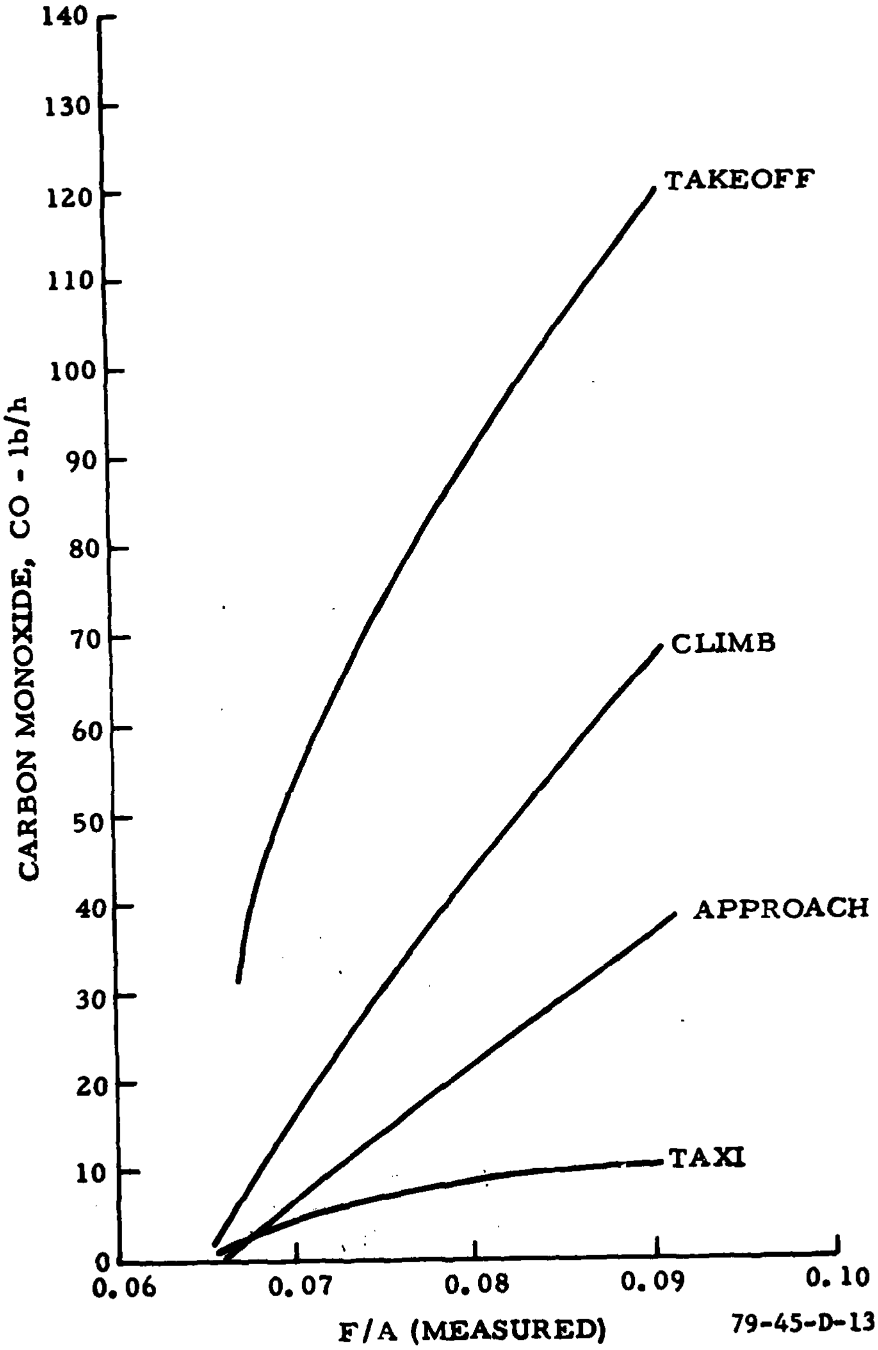


FIGURE D-13. NOMINAL SEA LEVEL STANDARD DAY EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-320-DIAD ENGINE—CARBON MONOXIDE

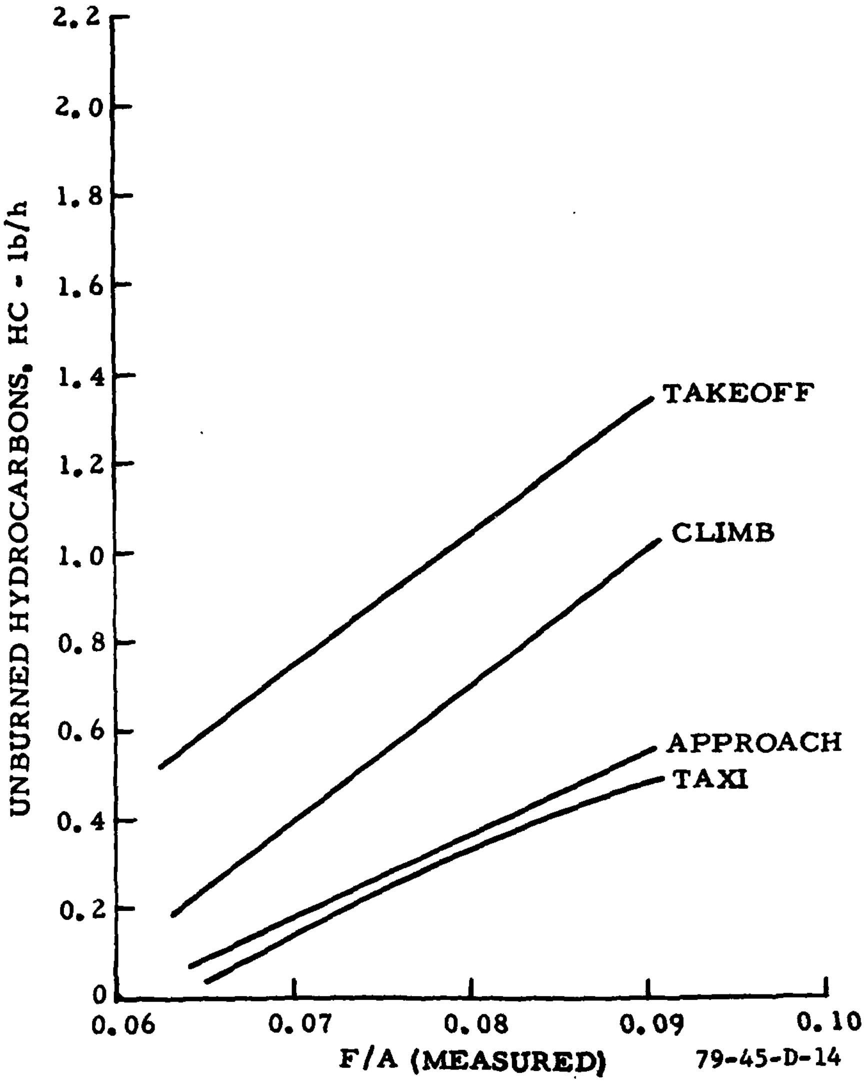


FIGURE D-14. NOMINAL SEA LEVEL STANDARD DAY EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-320-DIAD ENGINE—UNBURNED HYDROCARBONS

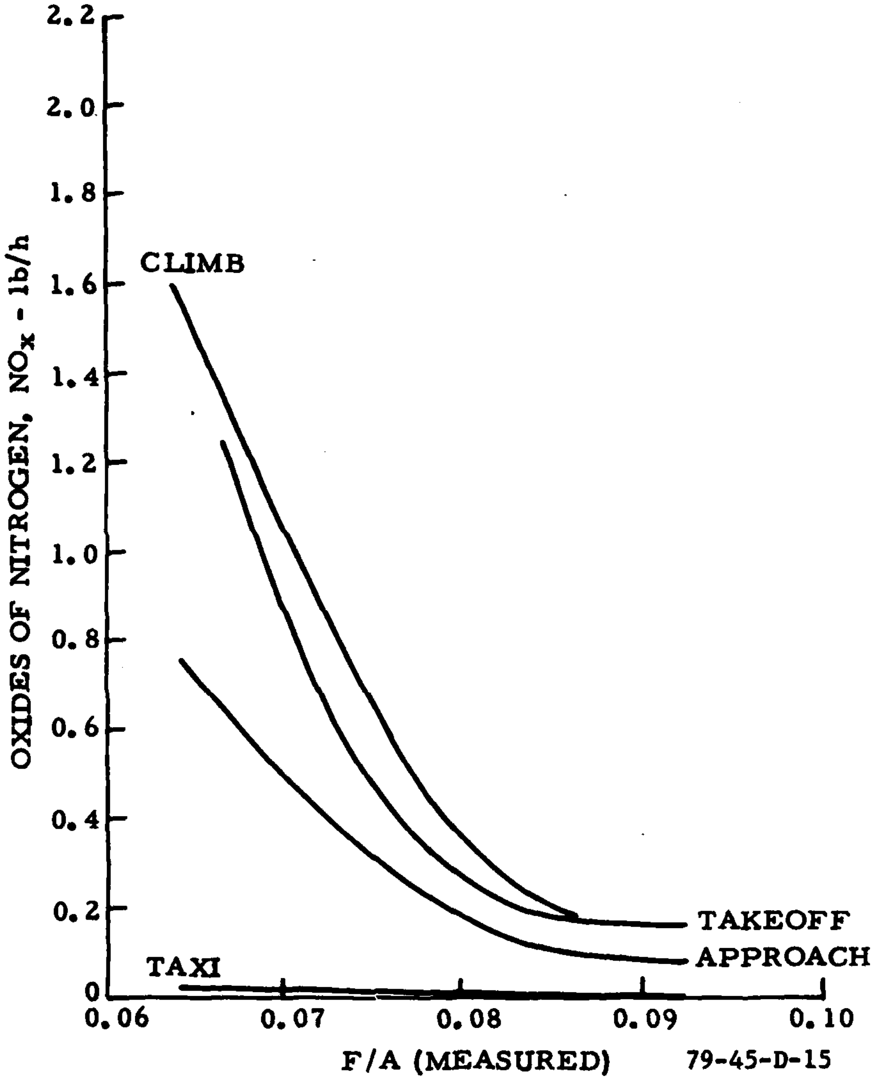


FIGURE D-15. NOMINAL SEA LEVEL STANDARD DAY EMISSIONS CHARACTERISTICS FOR AN AVCO LYCOMING IO-320-DIAD ENGINE--OXIDES OF NITROGEN

TABLE D-1. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #1- (NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

	Run No.	29	30	31	32	33
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		30.23	30.23	30.23	30.23	30.23
2. Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030	0.0030
3. Induct. Air Temp.-°F		46	44	45	45	45
4. Cooling Air Temp.-°F		106	41	40	39	87
5. Induct. Air Press.-inHgA		30.64	30.60	30.63	30.39	30.64
6. Engine Speed - RPM		1200	2700	2430	2350	1200
7. Manifold Air Press.-inHgA		10.2	29.3	26.0	18.0	9.9
8. Induct. Air Density-lb/ft^3		0.0802	0.0805	0.0804	0.0798	0.0804
9. Fuel Flow, W_f-lb/h		8.3	89.0	59.0	35.0	8.3
10. Airflow, W_a-lb/h		101.8	1109.0	754.0	438.0	101.9
11. F/A (Measured) = 9 / 10		0.0815	0.0803	0.0782	0.0799	0.0815
12. Max. Cht - °F		384	443	414	336	346
13. Avg. Cht - °F		362	438	410	330	328
14. Min. Cht - °F		351	432	406	324	321
15. EGT - °F		536	1292	1270	1104	558
16. Torque, lb-ft		28	322	260	134	29
17. Obs. Bhp		6.4	166	120	60	6.6
18. % CO_2 (Dry)		8.39	8.74	10.68	10.23	8.13
19. % CO (Dry)		8.84	8.80	5.58	6.33	9.55
20. % O_2 (Dry)		0.72	0.20	0.23	0.22	0.30
21. HC-ppm (Wet)		6873	1550	1396	1525	4360
22. NO_x-ppm (Wet)		59	175	503	239	39
23. CO_2-lb/hr		13.1	148.2	118.3	66.2	12.8
24. CO-lb/hr		8.77	95.0	39.4	26.1	9.55
25. O_2-lb/hr		7.37	2.47	1.85	1.03	0.34
26. HC-lb/hr		0.44	1.08	0.66	0.42	0.28
27. NO_x-lb/hr		0.007	0.228	0.442	0.123	0.005
28. CO-lb/Mode		1.754	0.475	3.279	2.607	0.637
29. HC-lb/Mode		0.0883	0.0054	0.0547	0.0419	0.0187
30. NO_x-lb/Mode		0.0014	0.0011	0.0369	0.0123	0.0003

TABLE D-2. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #2- (NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

	Parameter	Run No. 35	36	37	38	39
	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1.	Act. Baro. - inHgA	30.28	30.28	30.28	30.28	30.28
2.	Spec. Hum. - lb/lb	0.0030	0.0030	0.0030	0.0030	0.0030
3.	Induct. Air Temp.-°F	54	53	53	53	53
4.	Cooling Air Temp.-°F	95	50	50	50	112
5.	Induct. Air Press.-inHgA	30.68	30.65	30.67	30.43	30.68
6.	Engine Speed - RPM	1200	2700	2430	2350	1200
7.	Manifold Air Press.-inHgA	10.2	29.3	26.0	18.0	10.1
8.	Induct. Air Density-lb/ft^3	0.0791	0.0792	0.0792	0.0785	0.0791
9.	Fuel Flow, W_f-lb/h	9.2	89.0	59.0	35.5	8.8
10.	Airflow, W_a-lb/h	102.8	1099.0	745.0	437.0	102.8
11.	F/A (Measured) = 9 / 10	0.0895	0.0810	0.0792	0.0812	0.0856
12.	Max. Cht - °F	381	450	429	354	336
13.	Avg. Cht - °F	362	448	428	348	320
14.	Min. Cht - °F	354	448	427	345	303
15.	EGT - °F	532	1285	1250	1083	528
16.	Torque, lb-ft	30	315	254	133	31
17.	Obs. Bhp	6.9	162	118	59.5	7.1
18.	% CO_2 (Dry)	6.94	8.54	10.16	9.69	6.95
19.	% CO (Dry)	10.29	9.13	6.50	7.01	10.02
20.	% O_2 (Dry)	1.65	0.53	0.47	0.70	1.81
21.	HC-ppm (Wet)	5539	1689	1508	1704	1122
22.	NO_x-ppm (Wet)	25	165	403	201	22
23.	CO_2-lb/hr	11.2	144.8	112.7	63.5	11.2
24.	CO-lb/hr	10.6	98.5	45.9	29.2	10.3
25.	O_2-lb/hr	1.94	6.53	3.79	3.33	2.12
26.	HC-lb/hr	0.37	1.17	0.70	0.47	0.07
27.	NO_x-lb/hr	0.003	0.214	0.352	0.104	0.003
28.	CO-lb/Mode	2.117	0.493	3.824	2.924	0.684
29.	HC-lb/Mode	0.0740	0.0059	0.0586	0.0470	0.0049
30.	NO_x-lb/Mode	0.0006	0.0011	0.0293	0.0104	0.0002

TABLE D-3. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #3- (NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

	Run No.	40	41	42	43	44
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		30.28	30.28	30.28	30.28	30.25
2. Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030	0.0030
3. Induct. Air Temp.-°F		55	55	55	55	55
4. Cooling Air Temp.-°F		123	54	52	52	100
5. Induct. Air Press.-inHgA		30.68	30.64	30.67	30.44	30.62
6. Engine Speed - RPM		1200	2700	2430	2350	1200
7. Manifold Air Press.-inHgA		9.9	29.3	26.0	18.0	9.8
8. Induct. Air Density-lb/ft^3		0.0790	0.0788	0.0789	0.0783	0.0788
9. Fuel Flow, W_f-lb/h		7.0	89.0	59.0	28.0	7.0
10. Airflow, W_a-lb/h		100.2	1082.0	733.0	421.0	99.2
11. F/A (Measured) = 9 / 10		0.0699	0.0823	0.0805	0.0665	0.0706
12. Max. Cht - °F		380	452	428	366	361
13. Avg. Cht - °F		356	449	426	358	337
14. Min. Cht - °F		336	446	425	354	316
15. EGT - °F		534	1274	1243	1226	548
16. Torque, lb-ft		31	314	254	126	30
17. Obs. Bhp		7.1	161	118	56	6.9
18. % CO_2 (Dry)		10.07	8.51	10.11	13.44	9.87
19. % CO (Dry)		5.04	9.21	6.56	0.97	5.40
20. % O_2 (Dry)		1.85	0.52	0.49	0.72	1.95
21. HC-ppm (Wet)		2048	1643	1540	571	2152
22. NO_x-ppm (Wet)		83	170	398	1210	73
23. CO_2-lb/hr		14.9	142.2	110.5	80.0	14.5
24. CO-lb/hr		4.73	97.9	45.6	3.67	5.05
25. O_2-lb/hr		1.98	6.32	3.89	3.11	2.08
26. HC-lb/hr		0.124	1.12	0.71	0.143	0.129
27. NO_x-lb/hr		0.009	0.218	0.343	0.568	0.008
28. CO-lb/Mode		0.947	0.490	3.803	0.367	0.337
29. HC-lb/Mode		0.0248	0.0056	0.0591	0.0143	0.0086
30. NO_x-lb/Mode		0.0019	0.0011	0.0286	0.0568	0.0005

TABLE D-4. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #4-
(NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

	Run No.	45	46	47	48	49
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		30.22	30.22	30.22	30.22	30.22
2. Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030	0.0030
3. Induct. Air Temp.-°F		45	45	45	45	45
4. Cooling Air Temp.-°F		111	43	40	40	96
5. Induct. Air Press.-inHgA		30.63	30.59	30.61	30.39	30.62
6. Engine Speed - RPM		1200	2700	2430	2325	1200
7. Manifold Air Press.-inHgA		10.0	29.3	26.0	18.0	9.9
8. Induct. Air Density-lb/ft^3		0.0804	0.0803	0.0803	0.0798	0.0804
9. Fuel Flow, W_f-lb/h		6.7	89.0	51.0	28.0	6.8
10. Airflow, W_a-lb/h		98.4	1099.0	746.0	428.0	96.5
11. F/A (Measured) = 9 / 10		0.0681	0.0810	0.0684	0.0654	0.0705
12. Max. Cht - °F		398	444	431	355	385
13. Avg. Cht - °F		374	438	426	344	368
14. Min. Cht - °F		362	430	419	338	352
15. EGT - °F		561	1295	1362	1241	552
16. Torque, lb-ft		29	323	255	125	29
17. Obs. Bhp		6.6	166	118	55	6.6
18. % CO_2 (Dry)		12.10	8.78	13.03	13.91	11.41
19. % CO (Dry)		3.72	8.94	2.08	0.44	4.82
20. % O_2 (Dry)		.24	0.20	0.27	0.44	0.24
21. HC-ppm (Wet)		1728	1547	964	902	2062
22. NO_x-ppm (Wet)		124	182	1782	1233	100
23. CO_2-lb/hr		17.2	147.9	138.3	83.7	16.1
24. CO-lb/hr		3.37	95.8	14.1	1.68	4.32
25. O_2-lb/hr		0.25	2.45	2.08	1.92	0.25
26. HC-lb/hr		0.10	1.07	0.43	0.23	0.12
27. NO_x-lb/hr		0.014	0.236	1.49	0.588	0.011
28. CO-lb/Mode		0.674	0.479	1.171	0.168	0.288
29. HC-lb/Mode		0.0205	0.0054	0.0359	0.0230	0.0080
30. NO_x-lb/Mode		0.0028	0.0012	0.1242	0.0588	0.0007

TABLE D-5. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #5-
(NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

Parameter	Run No. / Mode	50 Taxi Out	51 Takeoff	52 Climb	53 Approach	54 Taxi In
1. Act. Baro. - inHgA		30.07	30.07	30.07	30.07	30.07
2. Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030	0.0030
3. Induct. Air Temp.-°F		58	55	54	53	53
4. Cooling Air Temp.-°F		115	49	47	47	84
5. Induct. Air Press.-inHgA		30.41	30.32	30.36	30.15	30.42
6. Engine Speed - RPM		1200	2700	2430	2350	1200
7. Manifold Air Press.-inHgA		10.3	29.3	26.0	18.0	9.8
8. Induct. Air Density-lb/ft^3		0.0778	0.0780	0.0783	0.0779	0.0786
9. Fuel Flow, W_f-lb/h		8.3	90.0	58.5	33.5	8.2
10. Airflow, W_a-lb/h		102.0	1045.0	709.0	403.0	102.0
11. F/A (Measured) = 9 / 10		0.0814	0.0861	0.0825	0.0831	0.0804
12. Max. Cht - °F		374	450	435	348	341
13. Avg. Cht - °F		353	441	431	339	327
14. Min. Cht - °F		339	433	426	333	318
15. EGT - °F		550	1306	1290	1102	575
16. Torque, lb-ft		24	322	260	126	25
17. Obs. Bhp		5.5	166	120	56	5.7
18. % CO_2 (Dry)		8.96	9.18	11.31	10.76	9.03
19. % CO (Dry)		7.65	8.95	5.38	6.30	8.47
20. % O_2 (Dry)		1.43	0.19	0.23	0.24	0.29
21. HC-ppm (Wet)		8225	1396	1189	1471	3296
22. NO_x-ppm (Wet)		116	228	695	333	57
23. CO_2-lb/hr		13.9	147.8	118.3	64.6	14.0
24. CO-lb/hr		7.55	91.7	35.8	24.1	8.39
25. O_2-lb/hr		1.61	2.22	1.75	1.05	0.33
26. HC-lb/hr		0.53	0.94	0.53	0.38	0.21
27. NO_x-lb/hr		0.014	0.286	0.584	0.159	0.007
28. CO-lb/Mode		1.509	0.458	2.985	2.408	0.559
29. HC-lb/Mode		0.1059	0.0047	0.0445	0.0376	0.0141
30. NO_x-lb/Mode		0.0028	0.0014	0.0487	0.0159	0.0005

TABLE D-6. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #6-(NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

	Run No.	75	75	77	78	79
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. **Act. Baro. - inHgA**		30.40	30.40	30.40	30.40	30.40
2. **Spec. Hum. - lb/lb**		0.0030	0.0030	0.0030	0.0030	0.0030
3. **Induct. Air Temp.-°F**		41	41	40	40	40
4. **Cooling Air Temp.-°F**		86	40	39	39	79
5. **Induct. Air Press.-inHgA**		30.73	30.70	30.72	30.51	30.75
6. **Engine Speed - RPM**		1200	2700	2430	2350	1200
7. **Manifold Air Press.-inHgA**		9.7	29.3	26.0	18.0	9.7
8. **Induct. Air Density-lb/ft^3**		0.0813	0.0812	0.0814	0.0809	0.0815
9. **Fuel Flow, W_f-lb/h**		7.3	87.0	57.0	34.5	7.5
10. **Airflow, W_a-lb/h**		104.3	1074.0	755.0	436.0	99.9
11. **F/A (Measured) = 9 / 10**		0.0700	0.0810	0.0755	0.0791	0.0751
12. **Max. Cht - °F**		355	453	444	371	358
13. **Avg. Cht - °F**		332	450	441	360	332
14. **Min. Cht - °F**		307	445	438	355	307
15. **EGT - °F**		554	1343	1332	1145	559
16. **Torque, lb-ft**		29	327	262	142	29
17. **Obs. Bhp**		6.6	168	121	64	6.6
18. **% CO_2 (Dry)**		9.40	10.00	12.00	11.50	9.40
19. **% CO (Dry)**		9.00	8.00	4.00	5.10	8.80
20. **% O_2 (Dry)**		0.10	0.10	0.10	0.10	0.10
21. **HC-ppm (Wet)**		3300	1290	1020	1290	3000
22. **NO_x-ppm (Wet)**		75	305	1150	625	73
23. **CO_2-lb/hr**		15.1	163.9	131.3	73.7	14.4
24. **CO-lb/hr**		9.23	83.5	27.9	20.8	8.61
25. **O_2-lb/hr**		0.12	1.19	0.80	0.47	0.11
26. **HC-lb/hr**		0.21	0.87	0.48	0.35	0.19
27. **NO_x-lb/hr**		0.009	0.386	1.00	0.319	0.008
28. **CO-lb/Mode**		1.846	0.417	2.322	2.080	0.574
29. **HC-lb/Mode**		0.0430	0.0044	0.0396	0.0352	0.0125
30. **NO_x-lb/Mode**		0.0018	0.0019	0.0835	0.0319	0.0056

TABLE D-7. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #7- (NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

	Run No.	80	81	82	83	84
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		30.18	30.18	30.18	30.18	30.18
2. Spec. Hum. - lb/lb		0.0040	0.0040	0.0040	0.0040	0.0040
3. Induct. Air Temp.-°F		99	108	105	104	104
4. Cooling Air Temp.-°F		111	112	105	104	96
5. Induct. Air Press.-inHgA		30.16	30.89	30.93	30.71	30.16
6. Engine Speed - RPM		1200	2700	2430	2350	1200
7. Manifold Air Press.-inHgA		10.4	29.6	26.0	18.0	10.2
8. Induct. Air Density-lb/ft^3		0.0715	0.0721	0.0726	0.0722	0.0719
9. Fuel Flow, W_f-lb/h		8.7	90.0	58.0	32.5	7.9
10. Airflow, W_a-lb/h		111.5	1048.0	723.0	418.0	101.3
11. F/A (Measured) = 9 / 10		0.0780	0.0859	0.0802	0.0778	0.0780
12. Max. Cht - °F		346	447	443	369	363
13. Avg. Cht - °F		331	444	436	364	343
14. Min. Cht - °F		325	442	434	361	324
15. EGT - °F		557	1268	1255	1111	585
16. Torque, lb-ft		30	302	242	124	28
17. Obs. Bhp		6.9	155	112	55	6.4
18. % CO_2 (Dry)		7.47	8.01	10.17	10.24	7.94
19. % CO (Dry)		5.93	10.37	6.62	6.57	8.70
20. % O_2 (Dry)		4.62	0.20	0.22	0.21	1.67
21. HC-ppm (Wet)		28,341	1768	1461	1539	13,820
22. NO_x-ppm (Wet)		133	133	406	255	53
23. CO_2-lb/hr		12.5	131.3	109.4	63.6	12.4
24. CO-lb/hr		6.31	108.2	45.3	26.0	8.62
25. O_2-lb/hr		5.62	2.38	1.72	0.95	1.89
26. HC-lb/hr		1.97	1.19	0.66	0.40	0.87
27. NO_x-lb/hr		0.017	0.167	0.345	0.124	0.006
28. CO-lb/Mode		1.262	0.541	3.777	2.598	0.575
29. HC-lb/Mode		0.3939	0.0059	0.0553	0.0400	0.0582
30. NO_x-lb/Mode		0.0035	0.0008	0.0287	0.0124	0.0004

TABLE D-8. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-BASELINE #8-
(NO IDLE, FIVE MODE) SPARK SETTING 25° BTC

	Run No.	105	106	107	108	109
Parameter	Mode	Taxi Out	Takeoff	Climb	Approach	Taxi In
1. Act. Baro. - inHgA		29.72	29.72	29.72	29.72	29.72
2. Spec. Hum. - lb/lb		0.0055	0.0055	0.0055	0.0055	0.0055
3. Induct. Air Temp.-°F		93	99	93	92	95
4. Cooling Air Temp.-°F		99	100	90	92	88
5. Induct. Air Press.-inHgA		29.70	30.44	30.50	30.28	29.70
6. Engine Speed - RPM		1200	2700	2430	2330	1200
7. Manifold Air Press.-inHgA		11.6	29.6	26.0	18.0	10.9
8. Induct. Air Density-lb/ft^3		0.0712	0.0722	0.0731	0.0727	0.0709
9. Fuel Flow, W_f-lb/h		9.2	90.0	58.5	32.5	8.7
10. Airflow, W_a-lb/h		109.1	1037.0	721.0	400.0	102.9
11. F/A (Measured) = 9 / 10		0.0843	0.0868	0.0811	0.0812	0.0845
12. Max. Cht - °F		376	448	435	367	357
13. Avg. Cht - °F		360	443	428	360	349
14. Min. Cht - °F		346	437	421	355	338
15. EGT - °F		578	1272	1240	1086	613
16. Torque, lb-ft		30	300	238	118	27
17. Obs. Bhp		6.9	154	110	52	6.2
18. % CO_2 (Dry)		7.62	7.99	9.87	9.77	7.45
19. % CO (Dry)		7.87	10.37	7.12	7.35	11.16
20. % O_2 (Dry)		2.69	0.19	0.21	0.22	0.30
21. HC-ppm (Wet)		18,526	1618	1470	1647	6106
22. NO_x-ppm (Wet)		92	123	329	177	25
23. CO_2-lb/hr		12.6	129.4	106.3	58.6	12.1
24. CO-lb/hr		8.31	106.9	48.8	28.1	11.6
25. O_2-lb/hr		3.24	2.24	1.64	0.96	0.36
26. HC-lb/hr		1.29	1.08	0.67	0.42	0.40
27. NO_x-lb/hr		0.012	0.154	0.279	0.083	0.003
28. CO-lb/Mode		1.663	0.534	5.067	2.808	0.772
29. HC-lb/Mode		0.2576	0.0054	0.0556	0.0416	0.0267
30. NO_x-lb/Mode		0.0024	0.0008	0.0233	0.0083	0.0002

TABLE D-9. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-TAKEOFF MODE-SPARK SETTING 25° BTC

	Parameter	Run No.	8	9	10	11	12
		Mode	Takeoff	Takeoff	Takeoff	Takeoff	Takeoff
1.	Act. Baro. - inHgA		29.75	29.75	29.75	29.75	29.77
2.	Spec. Hum. - lb/lb		0.0040	0.0040	0.0040	0.0040	0.0040
3.	Induct. Air Temp.-°F		60	59	59	58	58
4.	Cooling Air Temp.-°F		59	57	57	56	56
5.	Induct. Air Press.-inHgA		30.11	30.11	30.10	30.10	30.11
6.	Engine Speed - RPM		2700	2700	2700	2700	2700
7.	Manifold Air Press.-inHgA		29.3	29.3	29.3	29.3	29.4
8.	Induct. Air Density-lb/ft^3		0.0767	0.0769	0.0769	0.0770	0.0770
9.	Fuel Flow, W_f-lb/h		88.0	83.0	78.0	73.0	68.0
10.	Airflow, W_a-lb/h		1065.0	1066.0	1059.0	1053.0	1053.9
11.	F/A (Measured) = 9 / 10		0.0826	0.0779	0.0737	0.0693	0.0646
12.	Max. Cht - °F		451	462	475	488	497
13.	Avg. Cht - °F		445	457	470	482	490
14.	Min. Cht - °F		438	454	465	476	483
15.	EGT - °F		1267	1293	1330	1372	1429
16.	Torque, lb-ft		307	308	310	310	308
17.	Obs. Bhp		158	158	159	159	158
18.	% CO_2 (Dry)		8.05	8.77	9.78	10.63	12.04
19.	% CO (Dry)		9.60	8.21	6.67	5.18	2.85
20.	% O_2 (Dry)		0.45	0.46	0.45	0.46	0.51
21.	HC-ppm (Wet)		1644	1467	1390	1539	1274
22.	NO_x-ppm (Wet)		149	230	403	690	1483
23.	CO_2-lb/hr		132.4	141.4	153.8	163.5	181.1
24.	CO-lb/hr		100.5	84.2	66.8	50.7	27.3
25.	O_2-lb/hr		5.38	5.39	5.15	5.14	5.58
26.	HC-lb/hr		1.11	0.97	0.90	0.98	0.80
27.	NO_x-lb/hr		0.188	0.285	0.489	0.818	1.74
28.	CO-lb/Mode		0.503	0.421	0.334	0.253	0.136
29.	HC-lb/Mode		0.0055	0.0049	0.0045	0.0049	0.0040
30.	NO_x-lb/Mode		0.0009	0.0014	0.0024	0.0041	0.0087

TABLE D-10. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-TAKEOFF MODE-SPARK SETTING 25° BTC

	Run No.	55	56	57	58	59
Parameter	**Mode**	**Takeoff**	**Takeoff**	**Takeoff**	**Takeoff**	**Takeoff**
1. Act. Baro. - inHgA		30.06	30.06	30.06	30.06	30.06
2. Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030	0.0030
3. Induct. Air Temp.-°F		51	49	49	48	48
4. Cooling Air Temp.-°F		48	48	47	47	48
5. Induct. Air Press.-inHgA		30.32	30.33	30.34	30.35	30.34
6. Engine Speed - RPM		2700	2700	2700	2700	2700
7. Manifold Air Press.-inHgA		29.3	29.3	29.3	29.3	29.3
8. Induct. Air Density-lb/ft^3		0.0786	0.0790	0.0790	0.0792	0.0792
9. Fuel Flow, W_f-lb/h		89.0	84.0	79.0	74.0	69.0
10. Airflow, W_a-lb/h		1064.0	1081.0	1088.0	1096.0	1082.0
11. F/A (Measured) = 9 / 10		0.0836	0.0777	0.0726	0.0675	0.0638
12. Max. Cht - °F		451	469	487	503	508
13. Avg. Cht - °F		447	463	475	489	494
14. Min. Cht - °F		442	458	465	479	485
15. EGT - °F		1314	1356	1394	1440	1481
16. Torque, lb-ft		324	325	326	325	322
17. Obs. Bhp		167	167	168	167	166
18. % CO_2 (Dry)		9.16	10.23	11.28	12.29	13.32
19. % CO (Dry)		8.82	7.07	5.08	3.64	1.78
20. % O_2 (Dry)		0.20	0.20	0.20	0.23	0.30
21. HC-ppm (Wet)		1463	1276	1114	966	783
22. NO_x-ppm (Wet)		242	418	729	1331	2075
23. CO_2-lb/hr		149.7	166.2	180.0	195.0	205.1
24. CO-lb/hr		91.7	73.1	51.6	36.8	17.4
25. O_2-lb/hr		2.38	2.36	2.32	2.65	3.36
26. HC-lb/hr		0.99	0.86	0.74	0.63	0.50
27. NO_x-lb/hr		0.306	0.526	0.904	1.63	2.50
28. CO-lb/Mode		0.459	0.366	0.258	0.184	0.087
29. HC-lb/Mode		0.0049	0.0043	0.0037	0.0032	0.0025
30. NO_x-lb/Mode		0.0015	0.0026	0.0045	0.0082	0.0125

TABLE D-11. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-TAKEOFF MODE-SPARK SETTING 25° BTC

	Run No.	85	86	87	88	89
Parameter	**Mode**	**Takeoff**	**Takeoff**	**Takeoff**	**Takeoff**	**Takeoff**
1. Act. Baro. - inHgA		30.18	30.18	30.18	30.18	30.14
2. Spec. Hum. - lb/lb		0.0040	0.0040	0.0040	0.0040	0.0040
3. Induct. Air Temp.-°F		103	96	97	98	97
4. Cooling Air Temp.-°F		98	90	92	96	92
5. Induct. Air Press.-inHgA		30.91	30.92	30.92	30.92	30.89
6. Engine Speed - RPM		2700	2700	2700	2700	2700
7. Manifold Air Press.-inHgA		29.6	29.6	29.6	29.6	29.6
8. Induct. Air Density-lb/ft^3		0.0728	0.0737	0.0736	0.0734	0.0735
9. Fuel Flow, W_f-lb/h		87.0	82.0	77.0	72.0	67.0
10. Airflow, W_a-lb/h		1051.0	1057.0	1061.0	1052.0	1049.0
11. F/A (Measured) = 9 / 10		0.0828	0.0776	0.0726	0.0684	0.0639
12. Max. Cht - °F		451	460	477	495	510
13. Avg. Cht - °F		446	454	468	483	496
14. Min. Cht - °F		443	450	463	475	486
15. EGT - °F		1274	1307	1344	1388	1465
16. Torque, lb-ft		303	304	304	303	303
17. Obs. Bhp		156	156	156	156	156
18. % CO_2 (Dry)		8.14	9.03	10.09	11.16	12.79
19. % CO (Dry)		10.21	8.64	6.87	5.05	2.37
20. % O_2 (Dry)		0.19	0.18	0.18	0.19	0.23
21. HC-ppm (Wet)		1643	1436	1229	1045	860
22. NO_x-ppm (Wet)		135	217	388	745	1636
23. CO_2-lb/hr		133.4	145.8	159.7	171.5	191.1
24. CO-lb/hr		106.5	88.8	69.2	49.4	22.5
25. O_2-lb/hr		2.27	2.11	2.07	2.12	2.50
26. HC-lb/hr		1.09	0.94	0.80	0.66	0.54
27. NO_x-lb/hr		0.168	0.267	0.470	0.879	1.91
28. CO-lb/Mode		0.533	0.444	0.346	0.247	0.113
29. HC-lb/Mode		0.0055	0.0047	0.0040	0.0033	0.0027
30. NO_x-lb/Mode		0.0008	0.0013	0.0023	0.0044	0.0095

TABLE D-12. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-CLIMB MODE-SPARK SETTING 25° BTC

Parameter	Run No.	13	14	15
	Mode	Climb	Climb	Climb
1. Act. Baro. - inHgA		29.77	29.77	29.77
2. Spec. Hum. - lb/lb		0.0040	0.0040	0.0030
3. Induct. Air Temp.-°F		58	58	58
4. Cooling Air Temp.-°F		56	56	56
5. Induct. Air Press.-inHgA		30.15	30.15	30.15
6. Engine Speed - RPM		2430	2430	2430
7. Manifold Air Press.-inHgA		26.0	26.0	26.0
8. Induct. Air Density-lb/ft^3		0.0771	0.0771	0.0771
9. Fuel Flow, W_f-lb/h		59.0	55.0	51.0
10. Airflow, W_a-lb/h		724.0	714.0	714.0
11. F/A (Measured) = 9 / 10		0.0815	0.0770	0.0714
12. Max. Cht - °F		428	433	444
13. Avg. Cht - °F		426	431	440
14. Min. Cht - °F		421	425	432
15. EGT - °F		1231	1272	1323
16. Torque, lb-ft		244	244	246
17. Obs. Bhp		113	113	114
18. % CO_2 (Dry)		9.43	10.44	-
19. % CO (Dry)		6.92	5.13	-
20. % O_2 (Dry)		0.74	0.75	-
21. HC-ppm (Wet)		1842	1540	-
22. NO_x-ppm (Wet)		332	609	-
23. CO_2-lb/hr		101.9	108.9	-
24. CO-lb/hr		47.6	34.1	-
25. O_2-lb/hr		5.81	5.69	-
26. HC-lb/hr		0.84	0.68	-
27. NO_x-lb/hr		0.284	0.505	-
28. CO-lb/Mode		3.965	2.842	-
29. HC-lb/Mode		0.0701	0.0568	-
30. NO_x-lb/Mode		0.0236	0.0421	-

TABLE D-13. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-CLIMB MODE-SPARK SETTING 25° BTC

	Run No.	60	61	62	63	64
Parameter	Mode	Climb	Climb	Climb	Climb	Climb
1. Act. Baro. - inHgA		30.42	30.42	30.42	30.42	30.40
2. Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030	0.0030
3. Induct. Air Temp.-°F		46	44	43	42	41
4. Cooling Air Temp.-°F		38	38	39	39	39
5. Induct. Air Press.-inHgA		30.72	30.74	30.72	30.74	30.72
6. Engine Speed - RPM		2430	2430	2430	2430	2430
7. Manifold Air Press.-inHgA		26.0	26.0	26.0	26.0	26.0
8. Induct. Air Density-lb/ft^3		0.0805	0.0808	0.0809	0.0812	0.0813
9. Fuel Flow, W_f-lb/h		54.5	50.5	46.5	42.5	38.5
10. Airflow, W_a-lb/h		751.0	742.0	753.0	722.0	795.0
11. F/A (Measured) = 9 / 10		0.0726	0.0681	0.0618	0.0589	0.0484
12. Max. Cht - °F		410	430	432	409	380
13. Avg. Cht - °F		408	428	426	393	362
14. Min. Cht - °F		407	425	417	369	340
15. EGT - °F		1318	1375	1410	1385	1394
16. Torque, lb-ft		262	258	252	230	178
17. Obs. Bhp		121	119	117	106	82
18. % CO_2 (Dry)		12.10	13.60	14.00	13.00	11.40
19. % CO (Dry)		4.21	2.00	0.20	0.00	0.00
20. % O_2 (Dry)		0.24	0.20	0.60	2.40	4.80
21. HC-ppm (Wet)		1051	810	375	135	60
22. NO_x-ppm (Wet)		1128	1950	2400	2050	525
23. CO_2-lb/hr		132.6	144.3	147.8	132.6	129.4
24. CO-lb/hr		29.4	13.5	1.34	-	-
25. O_2-lb/hr		1.91	1.54	4.61	17.8	39.6
26. HC-lb/hr		0.482	0.360	0.168	0.058	0.028
27. NO_x-lb/hr		0.967	1.62	2.01	1.64	0.458
28. CO-lb/Mode		2.447	1.125	0.112	-	-
29. HC-lb/Mode		0.0401	0.0300	0.0140	0.0048	0.0023
30. NO_x-lb/Mode		0.0806	0.1351	0.1672	0.1366	0.0381

TABLE D-14. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-CLIMB MODE-SPARK SETTING 25° BTC

	Run No.	90	91	92	93	94
Parameter	Mode	Climb	Climb	Climb	Climb	Climb
1. Act. Baro. - inHgA		30.14	30.14	30.14	30.14	30.14
2. Spec. Hum. - lb/lb		0.0040	0.0040	0.0040	0.0040	0.0040
3. Induct. Air Temp.-°F		96	93	94	95	93
4. Cooling Air Temp.-°F		94	90	92	95	89
5. Induct. Air Press.-inHgA		30.92	30.91	30.91	30.91	30.92
6. Engine Speed - RPM		2430	2430	2430	2430	2430
7. Manifold Air Press.-inHgA		26.0	26.0	26.0	26.0	26.0
8. Induct. Air Density-lb/ft^3		0.0737	0.0741	0.0739	0.0738	0.0741
9. Fuel Flow, W_f-lb/h		60.0	56.0	52.0	48.0	44.0
10. Airflow, W_a-lb/h		730.0	720.0	731.0	713.0	720.0
11. F/A (Measured) = 9 / 10		0.0822	0.0778	0.0711	0.0673	0.0611
12. Max. Cht - °F		439	442	448	453	449
13. Avg. Cht - °F		432	436	443	447	431
14. Min. Cht - °F		426	429	436	441	414
15. EGT - °F		1256	1287	1327	1375	1400
16. Torque, lb-ft		241	245	243	238	223
17. Obs. Bhp		112	113	112	110	103
18. % CO_2 (Dry)		9.84	11.11	12.09	13.15	13.42
19. % CO (Dry)		7.20	5.09	3.53	1.69	0.18
20. % O_2 (Dry)		0.23	0.22	0.22	0.29	1.10
21. HC-ppm (Wet)		1520	1249	1097	826	288
22. NO_x-ppm (Wet)		347	695	1128	1737	2036
23. CO_2-lb/hr		107.7	117.0	127.1	132.7	135.2
24. CO-lb/hr		50.2	34.1	23.6	10.9	1.15
25. O_2-lb/hr		1.83	1.69	1.68	2.13	8.06
26. HC-lb/hr		0.70	0.56	0.49	0.35	0.123
27. NO_x-lb/hr		0.300	0.582	0.937	1.38	1.63
28. CO-lb/Mode		4.179	2.844	1.969	0.905	0.096
29. HC-lb/Mode		0.0585	0.0466	0.0406	0.0293	0.0103
30. NO_x-lb/Mode		0.0250	0.0485	0.0780	0.1152	0.1355

TABLE D-15. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-APPROACH MODE-SPARK SETTING 25° BTC

Parameter	Run No. / Mode	18	19	20	21
		Approach	Approach	Approach	Approach
1. Act. Baro. - inHgA		30.23	30.23	30.23	30.23
2. Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030
3. Induct. Air Temp.-°F		51	50	49	48
4. Cooling Air Temp.-°F		41	40	40	40
5. Induct. Air Press.-inHgA		30.40	30.39	30.40	30.41
6. Engine Speed - RPM		2350	2350	2325	2240
7. Manifold Air Press.-inHgA		18.0	17.9	18.0	18.0
8. Induct. Air Density-lb/ft^3		0.0788	0.0790	0.0792	0.0793
9. Fuel Flow, W_f-lb/h		34.0	31.0	28.0	25.0
10. Airflow, W_a-lb/h		427.0	430.0	426.0	414.0
11. F/A (Measured) = 9 / 10		0.0796	0.0721	0.0657	0.0604
12. Max. Cht - °F		344	347	348	333
13. Avg. Cht - °F		337	338	338	322
14. Min. Cht - °F		332	332	334	317
15. EGT - °F		1122	1170	1243	1208
16. Torque, lb-ft		132	131	124	110
17. Obs. Bhp		59	59	55	47
18. % CO_2 (Dry)		10.74	12.31	13.58	13.02
19. % CO (Dry)		5.75	3.09	0.52	0.10
20. % O_2 (Dry)		0.23	0.26	0.46	1.65
21. HC-ppm (Wet)		1390	1124	372	153
22. NO_x-ppm (Wet)		339	731	1117	857
23. CO_2-lb/hr		67.6	76.0	81.2	75.6
24. CO-lb/hr		23.0	12.1	1.98	0.37
25. O_2-lb/hr		1.05	1.17	2.00	6.97
26. HC-lb/hr		0.372	0.294	0.094	0.038
27. NO_x-lb/hr		0.170	0.358	0.530	0.393
28. CO-lb/Mode		2.303	1.214	0.198	0.037
29. HC-lb/Mode		0.0372	0.0294	0.0094	0.0038
30. NO_x-lb/Mode		0.0170	0.0358	0.0530	0.0393

TABLE D-16. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-APPROACH MODE-SPARK SETTING 25° BTC

	Run No.	65	66	67	68	69
Parameter	Mode	Approach	Approach	Approach	Approach	Approach
1. Act. Baro. - inHgA		30.06	30.06	30.06	30.06	30.05
2. Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030	0.0030
3. Induct. Air Temp.-°F		50	50	50	51	51
4. Cooling Air Temp.-°F		50	49	48	48	48
5. Induct. Air Press.-inHgA		30.08	30.07	30.07	30.10	30.11
6. Engine Speed - RPM		2350	2350	2350	2350	2275
7. Manifold Air Press.-inHgA		18.0	18.0	17.9	18.0	18.0
8. Induct. Air Density-lb/ft^3		0.0782	0.0781	0.0781	0.0781	0.0781
9. Fuel Flow, W_f-lb/h		34.0	32.0	30.0	28.0	26.0
10. Airflow, W_a-lb/h		425.0	425.0	424.0	423.0	413.0
11. F/A (Measured) = 9 / 10		0.0800	0.0753	0.0708	0.0662	0.0630
12. Max. Cht - °F		362	357	360	356	348
13. Avg. Cht - °F		354	350	352	346	336
14. Min. Cht - °F		346	345	346	341	331
15. EGT - °F		1120	1161	1198	1243	1221
16. Torque, lb-ft		134	134	131	125	117
17. Obs. Bhp		60	60	59	56	51
18. % CO_2 (Dry)		11.03	12.38	13.32	14.06	13.54
19. % CO (Dry)		5.24	3.37	1.58	0.29	0.11
20. % O_2 (Dry)		0.21	0.23	0.26	0.58	1.57
21. HC-ppm (Wet)		1406	1228	986	328	162
22. NO_x-ppm (Wet)		474	927	1379	1656	1440
23. CO_2-lb/hr		68.7	75.9	80.7	83.7	78.9
24. CO-lb/hr		20.8	13.1	4.89	1.10	0.41
25. O_2-lb/hr		0.95	1.02	1.18	2.51	6.65
26. HC-lb/hr		0.375	0.322	0.253	0.083	0.040
27. NO_x-lb/hr		0.236	0.454	0.663	0.781	0.661
28. CO-lb/Mode		2.078	1.315	0.489	0.110	0.041
29. HC-lb/Mode		0.0375	0.0322	0.0253	0.0083	0.0040
30. NO_x-lb/Mode		0.0236	0.0454	0.0663	0.0781	0.0661

TABLE D-17. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-TAXI MODE-SPARK SETTING 25° BTC

	Run No.	95	96	97	98	99
Parameter	Mode	Approach	Approach	Approach	Approach	Approach
1. Act. Baro. - inHgA		30.14	30.14	30.14	30.14	30.12
2. Spec. Hum. - lb/lb		0.0040	0.0040	0.0040	0.0040	0.0035
3. Induct. Air Temp.-°F		92	93	92	91	92
4. Cooling Air Temp.-°F		91	93	90	90	93
5. Induct. Air Press.-inHgA		30.69	30.69	30.69	30.71	30.84
6. Engine Speed - RPM		2350	2350	2300	2250	2175
7. Manifold Air Press.-inHgA		18.0	18.0	18.0	18.0	18.1
8. Induct. Air Density-lb/ft^3		0.0737	0.0735	0.0737	0.0739	0.0740
9. Fuel Flow, W_f-lb/h		34.0	31.0	28.0	25.0	22.0
10. Airflow, W_a-lb/h		410.0	414.0	413.0	400.0	401.0
11. F/A (Measured) = 9 / 10		0.0829	0.0749	0.0678	0.0625	0.0549
12. Max. Cht - °F		365	370	374	368	356
13. Avg. Cht - °F		358	363	368	358	346
14. Min. Cht - °F		354	359	366	352	339
15. EGT - °F		1088	1154	1228	1232	1172
16. Torque, lb-ft		121	122	121	110	100
17. Obs. Bhp		54	55	53	47	41
18. % CO_2 (Dry)		9.75	11.63	13.45	13.52	12.12
19. % CO (Dry)		7.36	4.25	1.28	0.12	0.07
20. % O_2 (Dry)		0.21	0.21	0.27	1.10	3.30
21. HC-ppm (Wet)		1695	1268	712	172	77
22. NO_x-ppm (Wet)		189	526	1125	1051	588
23. CO_2-lb/hr		60.0	69.8	78.5	75.8	68.7
24. CO-lb/hr		28.8	16.2	4.76	0.43	0.25
25. O_2-lb/hr		0.94	0.92	1.15	4.48	13.61
26. HC-lb/hr		0.441	0.323	0.176	0.041	0.018
27. NO_x-lb/hr		0.0392	0.251	0.521	0.467	0.260
28. CO-lb/Mode		2.881	1.624	0.476	0.043	0.025
29. HC-lb/Mode		0.0441	0.0323	0.0176	0.0041	0.0018
30. NO_x-lb/Mode		0.0092	0.0251	0.0521	0.0467	0.0260

TABLE D-18. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-TAXI MODE-SPARK SETTING 25° BTC

Parameter	Run No. / Mode	70	71	72	73	74
		Taxi	Taxi	Taxi	Taxi	Taxi
1. Act. Baro. - inHgA		30.06	30.06	30.06	30.06	30.06
2. Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030	0.0030
3. Induct. Air Temp.-°F		49	49	49	49	50
4. Cooling Air Temp.-°F		99	102	109	112	113
5. Induct. Air Press.-inHgA		30.24	30.20	30.20	30.21	30.22
6. Engine Speed - RPM		1200	1200	1200	1200	1200
7. Manifold Air Press.-inHgA		10.0	10.0	10.1	10.1	10.2
8. Induct. Air Density-lb/ft^3		0.0787	0.0786	0.0786	0.0787	0.0785
9. Fuel Flow, W_f-lb/h		8.6	8.1	7.6	7.1	6.7
10. Airflow, W_a-lb/h		93.6	93.6	93.6	98.2	95.0
11. F/A (Measured) = 9 / 10		0.0919	0.0865	0.0812	0.0723	0.0705
12. Max. Cht - °F		362	384	405	409	421
13. Avg. Cht - °F		343	366	378	374	387
14. Min. Cht - °F		336	354	353	351	356
15. EGT - °F		568	544	524	554	558
16. Torque, lb-ft		28	28	27	28	26
17. Obs. Bhp		6.4	6.4	6.2	6.4	5.9
18. % CO_2 (Dry)		8.30	9.00	9.80	10.00	11.84
19. % CO (Dry)		9.51	8.01	5.63	4.06	2.72
20. % O_2 (Dry)		0.28	0.28	1.98	2.66	1.13
21. HC-ppm (Wet)		3928	6015	9718	9364	3604
22. NO_x-ppm (Wet)		54	79	117	158	213
23. CO_2-lb/hr		12.0	12.7	13.6	14.4	16.1
24. CO-lb/hr		8.75	7.21	4.99	3.71	2.36
25. O_2-lb/hr		0.29	0.29	2.00	2.77	1.12
26. HC-lb/hr		0.241	0.362	0.574	0.560	0.207
27. NO_x-lb/hr		0.006	0.009	0.013	0.018	0.023
28. CO-lb/Mode		2.333	1.923	1.330	0.989	0.629
29. HC-lb/Mode		0.0642	0.0966	0.1530	0.1493	0.0552
30. NO_x-lb/Mode		0.0017	0.0024	0.0034	0.0047	0.0061

TABLE D-19. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-TAXI MODE-SPARK SETTING 25° BTC

	Run No.	23	24	25	26
Parameter	**Mode**	**Taxi**	**Taxi**	**Taxi**	**Taxi**
1. Act. Baro. - inHgA		30.23	30.23	30.23	30.23
2. Spec. Hum. - lb/lb		0.0030	0.0030	0.0030	0.0030
3. Induct. Air Temp.-°F		49	48	48	48
4. Cooling Air Temp.-°F		88	101	104	104
5. Induct. Air Press.-inHgA		30.43	30.43	30.43	30.43
6. Engine Speed - RPM		1200	1200	1200	1200
7. Manifold Air Press.-inHgA		10.0	9.9	9.9	10.0
8. Induct. Air Density-lb/ft^3		0.0792	0.0794	0.0794	0.0794
9. Fuel Flow, W_f-lb/h		8.1	7.6	7.1	6.6
10. Airflow, W_a-lb/h		98.5	98.6	95.9	97.7
11. F/A (Measured) = 9 / 10		0.0822	0.0771	0.0740	0.0676
12. Max. Cht - °F		352	379	396	406
13. Avg. Cht - °F		338	364	382	388
14. Min. Cht - °F		328	349	362	369
15. EGT - °F		538	533	540	559
16. Torque, lb-ft		30	29	28	29
17. Obs. Bhp		6.9	6.6	6.4	6.6
18. % CO_2 (Dry)		8.18	9.30	10.45	11.74
19. % CO (Dry)		9.77	7.97	6.17	4.09
20. % O_2 (Dry)		0.30	0.27	0.26	0.23
21. HC-ppm (Wet)		4331	3027	2461	1970
22. NO_x-ppm (Wet)		41	63	80	108
23. CO_2-lb/hr		12.5	13.9	14.8	16.6
24. CO-lb/hr		9.55	7.58	5.58	3.69
25. O_2-lb/hr		0.333	0.294	0.269	0.237
26. HC-lb/hr		0.270	0.185	0.145	0.115
27. NO_x-lb/hr		0.0048	0.0072	0.0087	0.0117
28. CO-lb/Mode		2.534	2.021	1.487	0.984
29. HC-lb/Mode		0.0720	0.0494	0.0387	0.0307
30. NO_x-lb/Mode		0.0013	0.0019	0.0023	0.0031

TABLE D-20. AVCO LYCOMING IO-320-DIAD ENGINE (S/N 889-X) NAFEC TEST DATA-TAXI MODE-SPARK SETTING 25° BTC

Parameter	Run No.	100	101	102	103	104
	Mode	Taxi	Taxi	Taxi	Taxi	Taxi
1. Act. Baro. - inHgA		29.72	29.72	29.72	29.72	29.72
2. Spec. Hum. - lb/lb		0.0035	0.0035	0.0035	0.0035	0.0035
3. Induct. Air Temp.-°F		94	91	90	89	88
4. Cooling Air Temp.-°F		102	102	102	107	105
5. Induct. Air Press.-inHgA		29.71	29.71	29.71	29.72	29.71
6. Engine Speed - RPM		1200	1200	1200	1200	1200
7. Manifold Air Press.-inHgA		11.6	11.9	12.0	11.9	11.8
8. Induct. Air Density-lb/ft^3		0.0711	0.0715	0.0716	0.0717	0.0718
9. Fuel Flow, W_f-lb/h		9.4	9.0	8.4	7.9	7.4
10. Airflow, W_a-lb/h		114.0	117.7	117.8	116.5	108.8
11. F/A (Measured) = 9 / 10		0.0825	0.0765	0.0713	0.0678	0.0680
12. Max. Cht - °F		371	404	418	426	424
13. Avg. Cht - °F		360	382	390	388	396
14. Min. Cht - °F		342	354	363	366	377
15. EGT - °F		562	559	555	553	542
16. Torque, lb-ft		32	31	30	28	26
17. Obs. Bhp		7.3	7.1	6.9	6.4	5.9
18. % CO_2 (Dry)		7.07	7.52	7.76	8.32	7.99
19. % CO (Dry)		7.51	6.28	5.28	4.65	5.34
20. % O_2 (Dry)		4.42	4.13	4.75	4.55	4.44
21. HC-ppm (Wet)		26,695	21,588	17,381	11,630	9,097
22. NO_x-ppm (Wet)		98	141	175	179	137
23. CO_2-lb/hr		12.4	13.3	13.6	14.3	13.0
24. CO-lb/hr		8.39	7.06	5.90	5.10	5.51
25. O_2-lb/hr		5.64	5.31	6.06	5.70	5.24
26. HC-lb/hr		1.93	1.57	1.25	0.812	0.593
27. NO_x-lb/hr		0.0132	0.0192	0.0234	0.0234	0.0168
28. CO-lb/Mode		2.237	1.883	1.572	1.359	1.470
29. HC-lb/Mode		0.5144	0.4194	0.3316	0.2164	0.1581
30. NO_x-lb/Mode		0.0035	0.0051	0.0062	0.0062	0.0045